Time-Frequency Bibliography

Reference numbers in the text of this book refer to the local "References" list at the end of the current Chapter (in Part I and Chapter 16) or the current Article (elsewhere). The following "time-frequency" bibliography is an alphabetical listing of all publicly-available sources that appear in the local "References" lists, excluding application-specific references not pertaining to the time-frequency field, and adding some other important references which, because of space and scope restrictions, are not cited in the text. It is intended as a snapshot, dated 2003, of the most important references in TFSAP and its applications.

If the same source appears in two or more local "References" lists, the reference numbers generally differ, but the substantive details have been verified and harmonized.¹

- [1] K. Abed-Meraim and B. Barkat. "Blind source separation using the time-frequency distribution of the mixture signal". In *Proc. Second IEEE Internat. Symp. on Signal Processing and Information Technology (ISSPIT'02)*, volume 2, pages 663–666, Marrakech, Morocco, 18–21 December 2002.
- [2] K. Abed-Meraim, N. Linh-Trung, V. Sucic, F. Tupin, and B. Boashash. "An image processing approach for underdetermined blind separation of nonstationary sources". In *Proc. Third Internat. Symp. on Image & Signal Processing and Analysis (ISPA-03)*, Rome, 18–20 September 2003.
- [3] S. S. Abeysekera and B. Boashash. "Methods of signal classification using the images produced by the Wigner-Ville distribution". *Pattern Recognition Letters*, 12(11):717–729, November 1991.
- [4] R. Adelino and F. da Silva. "Atomic decomposition with evolutionary pursuit". *Digital Signal Processing: A Review Journal*, 13(2):317–337, April 2003.
- [5] O. Akay and G. F. Boudreaux-Bartels. "Unitary and Hermitian fractional operators and their relation to the fractional Fourier transform". *IEEE Signal Processing Letters*, 5(12):312–314, December 1998.
- [6] O. Akay and G. F. Boudreaux-Bartels. "Fractional convolution and correlation via operator methods and an application to detection of linear FM signals". *IEEE Trans. Signal Processing*, 49(5):979–993, May 2001.
- [7] L. B. Almeida. "The fractional Fourier transform and time-frequency representations". *IEEE Trans. Signal Processing*, 42(11):3084–3091, November 1994.
- [8] R. A. Altes. "Detection, estimation and classification with spectrograms". *J. Acoustical Soc. of America*, 67(4):1232–1246, April 1980.

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¹A consolidated bibliographic database was compiled from the references supplied by contributing authors. Local reference lists were regenerated from that database using the bibunits package (v. 2.0 by Thorsten Hansen).

- [9] R. A. Altes. "Wideband, proportional-bandwidth Wigner-Ville analysis". *IEEE Trans. Acoustics, Speech, & Signal Processing*, 38(6):1005–1012, June 1990.
- [10] R. A. Altes and E. L. Titlebaum. "Bat signals as optimally Doppler tolerant waveforms". J. Acoustical Soc. of America, 48:1014–1020, October 1970.
- [11] J. Altmann and J. Mathew. "DWPA multiple band-pass filtering for extraction of bearing fault transients from a strong continuous signal". In *Proc. Asia-Pacific Vibration Conference*, volume 2, pages 772–776, Hangzhou, China, October–November 2001.
- [12] M. G. Amin. "Time-frequency spectrum analysis and estimation for non-stationary random processes". In B. Boashash, editor, *Time-Frequency Signal Analysis: Methods and Applications*, chapter 9, pages 208–232. Longman-Cheshire/Wiley, Melbourne/N.Y., 1992
- [13] M. G. Amin. "Spectral decomposition of time-frequency distribution kernels". *IEEE Trans. Signal Processing*, 42(5):1156–1165, May 1994.
- [14] M. G. Amin. "Minimum-variance time-frequency distribution kernels for signals in additive noise". *IEEE Trans. Signal Processing*, 44(9):2352–2356, September 1996.
- [15] M. G. Amin. "Interference mitigation in spread-spectrum communication systems using time-frequency distributions". *IEEE Trans. Signal Processing*, 45(1):90–102, January 1997
- [16] M. G. Amin and A. N. Akansu. "Time-frequency for interference excision in spread-spectrum communications". In G. B. Giannakis, editor, "Highlights of Signal Processing for Communications", *IEEE Signal Processing Magazine*, volume 16(2). IEEE, March 1999.
- [17] M. G. Amin, A. Belouchrani, and Y. Zhang. "The spatial ambiguity function and its applications". *IEEE Signal Processing Letters*, 7(6):138–140, June 2000.
- [18] M. G. Amin, C. Wang, and A. R. Lindsey. "Optimum interference excision in spread-spectrum communications using open-loop adaptive filters". *IEEE Trans. Signal Processing*, 47(7):1966–1976, July 1999.
- [19] M. G. Amin and Y. Zhang. "Direction finding based on spatial time-frequency distribution matrices". *Digital Signal Processing: A Review Journal*, 10(4):325–339, October 2000.
- [20] J. C. Andrieux, R. Feix, G. Mourgues, P. Bertrand, B. Izrar, and V. T. Nguyen. "Optimum smoothing of the Wigner-Ville distribution". *IEEE Trans. Acoustics, Speech*, & Signal Processing, 35(6):764–769, June 1987.
- [21] L. Angrisani and M. D'Arco. "A measurement method based on a modified version of the chirplet transform for instantaneous frequency estimation". *IEEE Trans. Instrumentation & Measurement*, 51(4):704–711, August 2002.
- [22] M. J. Arnold, M. Roessgen, and B. Boashash. "Filtering real signals through frequency modulation and peak detection in the time-frequency plane". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'94)*, volume 3, pages 345–348, Adelaide, Australia, 19–22 April 1994.
- [23] H. Artés, G. Matz, and F. Hlawatsch. "Unbiased scattering function estimation during data transmission". In *Proc. IEEE Vehicular Technology Conf. (VTC'99-Fall)*, pages 1535–1539, Amsterdam, 19–22 September 1999.

- [24] F. Auger and P. Flandrin. "Improving the readability of time-frequency and time-scale representations by the reassignment method". *IEEE Trans. Signal Processing*, 43(5):1068–1089, May 1995.
- [25] G. Azemi, B. Senadji, and B. Boashash. "A novel estimator for the velocity of a mobile base station in a micro-cellular system". In *Proc. IEEE Internat. Symp. on Circuits and Systems (ISCAS 03)*, volume 2, pages 212–215, Bangkok, 25–28 May 2003.
- [26] J. S. Bach (1685-1750). St Matthew Passion, nos. 2–3 (ed. A. Van Ryckeghem). GMD Music Archive, http://www.gmd.de/Misc/Music/scores/Introduction.html, 2000. Continued by Werner Icking Music Archive, http://icking-music-archive.sunsite.dk/.
- [27] R. Baraniuk, D. Jones, T. Brotherton, and S. L. Marple Jr. "Applications of adaptive time-frequency representations to underwater acoustic signal processing". In *Proc. 25th Asilomar Conf. on Signals, Systems, and Computers*, volume 2, pages 1109–1113, Pacific Grove, CA, 4–6 November 1991.
- [28] R. G. Baraniuk. "Covariant time-frequency representations through unitary equivalence". *IEEE Signal Processing Letters*, 3(3):79–81, March 1996.
- [29] R. G. Baraniuk. "Beyond time-frequency analysis: Energy densities in one and many dimensions". *IEEE Trans. Signal Processing*, 46(9):2305–2314, September 1998.
- [30] R. G. Baraniuk. "Joint distributions of arbitrary variables made easy". *J. of Multi-dimensional Systems & Signal Processing*, 9(4):341–348, October 1998. Special issue on time-frequency analysis.
- [31] R. G. Baraniuk and L. Cohen. "On joint distributions of arbitrary variables". *IEEE Signal Processing Letters*, 2(1):10–12, January 1995.
- [32] R. G. Baraniuk, P. Flandrin, A. J. E. M. Janssen, and O. J. J. Michel. "Measuring time-frequency information content using the Rényi entropies". *IEEE Trans. Information Theory*, 47(4):1391–1409, May 2001.
- [33] R. G. Baraniuk and D. L. Jones. "Signal-dependent time-frequency analysis using a radially Gaussian kernel". Signal Processing, 32(3):263–284, June 1993.
- [34] R. G. Baraniuk and D. L. Jones. "A signal-dependent time-frequency representation: Optimal kernel design". *IEEE Trans. Signal Processing*, 41(4):1589–1602, April 1993.
- [35] R. G. Baraniuk and D. L. Jones. "A signal-dependent time-frequency representation: Fast algorithm for optimal kernel design". *IEEE Trans. Signal Processing*, 42(1):134–146, January 1994.
- [36] R. G. Baraniuk and D. L. Jones. "Unitary equivalence: A new twist on signal processing". *IEEE Trans. Signal Processing*, 43(10):2269–2282, October 1995.
- [37] S. Barbarossa. "Detection and imaging of moving objects with synthetic aperture radar—Part 1: Optimal detection and parameter estimation theory". *IEE Proc.*, Part F: Radar & Signal Processing, 139(1):79–88, February 1992.
- [38] S. Barbarossa and O. Lemoine. "Analysis of nonlinear FM signals by pattern recognition of their time-frequency representation". *IEEE Signal Processing Letters*, 3(4):112–115, April 1996.
- [39] S. Barbarossa and A. Scaglione. "Autofocusing of SAR images based on the product high-order ambiguity function". *IEE Proc.: Radar, Sonar & Navigation*, 145(5):269–273, October 1998.

- [40] S. Barbarossa and A. Scaglione. "Adaptive time-varying cancellations of wideband interferences in spread-spectrum communications based on time-frequency distributions". *IEEE Trans. Signal Processing*, 47(4):957–965, April 1999.
- [41] S. Barbarossa and A. Scaglione. "On the capacity of linear time-varying channels". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'99)*, pages 2627–2630, Phoenix, AZ, 15–19 March 1999.
- [42] S. Barbarossa and A. Scaglione. "Time-varying fading channels". In G. B. Giannakis, Y. Hua, P. Stoica, and L. Tong, editors, *Signal Processing Advances in Wireless and Mobile Communications*, volume 2: "Trends in Single- and Multi-User Systems", chapter 1. Prentice-Hall, Upper Saddle River, NJ, 2001.
- [43] S. Barbarossa, A. Scaglione, and G. B. Giannakis. "Product high-order ambiguity function for multicomponent polynomial-phase signal modeling". *IEEE Trans. Signal Processing*, 46(3):691–708, March 1998.
- [44] B. Barkat. "Instantaneous frequency estimation of nonlinear frequency-modulated signals in the presence of multiplicative and additive noise". *IEEE Trans. Signal Processing*, 49(10):2214–2222, October 2001.
- [45] B. Barkat and K. Abed-Meraim. "A blind components separation procedure for FM signal analysis". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'02)*, volume 2, pages 1425–1428, Orlando, FL, 13–17 May 2002.
- [46] B. Barkat and B. Boashash. "Higher order PWVD and Legendre based time-frequency distribution". In *Proc. Sixth IEEE Internat. Workshop on Intelligent Signal Processing and Communication Systems (ISPACS'98)*, volume 2, pages 532–536, Melbourne, Australia, 5–6 November 1998.
- [47] B. Barkat and B. Boashash. "Design of higher order polynomial Wigner-Ville distributions". *IEEE Trans. Signal Processing*, 47(9):2608–2611, September 1999.
- [48] B. Barkat and B. Boashash. "Instantaneous frequency estimation of polynomial FM signals using the peak of the PWVD: Statistical performance in the presence of additive Gaussian noise". *IEEE Trans. Signal Processing*, 47(9):2480–2490, September 1999.
- [49] B. Barkat and B. Boashash. "A high-resolution quadratic time-frequency distribution for multicomponent signals analysis". *IEEE Trans. Signal Processing*, 49(10):2232–2239, October 2001.
- [50] H. O. Bartelt, K. H. Brenner, and A. W. Lohmann. "The Wigner distribution function and its optical production". *Optics Communications*, 32(1):32–38, January 1980.
- [51] M. J. Bastiaans. "Gabor's signal expansion and its relation to sampling of the sliding-window spectrum". In R. J. Marks II, editor, *Advanced Topics in Shannon Sampling and Interpolation Theory*, pages 1–35. Springer, New York, 1993.
- [52] M. J. Bastiaans. "Gabor's expansion and the Zak transform for continuous-time and discrete-time signals: Critical sampling and rational oversampling". Research Report 95-E-295, Eindhoven University of Technology, Eindhoven, Netherlands, 1995.
- [53] M. J. Bastiaans, T. Alieva, and L. Stanković. "On rotated time-frequency kernels". *IEEE Signal Processing Letters*, 9(11):378–381, November 2002.
- [54] M. J. Bastiaans and M. C. W. Geilen. "On the discrete Gabor transform and the discrete Zak transform". Signal Processing, 49(3):151–166, March 1996.

- [55] E. Bedrosian. "A product theorem for Hilbert transforms". *Proc. IEEE*, 51:686–689, 1963.
- [56] P. A. Bello. "Characterization of randomly time-variant linear channels". *IEEE Trans. Communication Systems*, 11(4):360–393, December 1963.
- [57] A. Belouchrani and M. G. Amin. "New approach for blind source separation using time frequency distributions". In *Proc. SPIE: Advanced Signal Processing Algorithms, Architectures and Implementations VI*, volume 2846, pages 193–203. Soc. of Photo-optical Instrumentation Engineers, Denver, CO, 4–9 August 1996.
- [58] A. Belouchrani and M. G. Amin. "Blind source separation using time-frequency distributions: Algorithm and asymptotic performance". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'97)*, volume 5, pages 3469–3472, Munich, 21–24 April 1997.
- [59] A. Belouchrani and M. G. Amin. "Blind source separation based on time-frequency signal representation". *IEEE Trans. Signal Processing*, 46(11):2888–2898, November 1998.
- [60] A. Belouchrani and M. G. Amin. "Time-frequency MUSIC: A new array signal processing method based on time-frequency signal representation". *IEEE Signal Processing Letters*, 6(5):109–110, May 1999.
- [61] A. Belouchrani, M. G. Amin, and K. Abed-Meraim. "Direction finding in correlated noise fields based on joint block-diagonalization of spatio-temporal correlation matrices". *IEEE Signal Processing Letters*, 4(9):266–268, September 1997.
- [62] M. Benidir. "Characterization of polynomial functions and application to time-frequency analysis". *IEEE Trans. Signal Processing*, 45(5):1351–1354, May 1997.
- [63] M. Benidir and A. Ouldali. "Polynomial phase signal analysis based on the polynomial derivatives decompositions". *IEEE Trans. Signal Processing*, 47(7):1954–1965, July 1999.
- [64] J. Bertrand and P. Bertrand. "Représentations temps-fréquence des signaux". Comptes rendus de l'Académie des Sciences, Paris, 299, Ser. 1:635–638, 1984.
- [65] J. Bertrand and P. Bertrand. "A tomographic approach to Wigner's function". Foundations of Physics, 17:397–405, 1987.
- [66] J. Bertrand and P. Bertrand. "Affine time-frequency distributions". In B. Boashash, editor, *Time-Frequency Signal Analysis: Methods and Applications*, chapter 5, pages 118–140. Longman-Cheshire/Wiley, Melbourne/N.Y., 1992.
- [67] J. Bertrand and P. Bertrand. "A class of affine Wigner functions with extended covariance properties". *J. of Mathematical Physics*, 33(7):2515–2527, July 1992.
- [68] J. Bertrand and P. Bertrand. "Symbolic calculus on the time-frequency half-plane". J. of Mathematical Physics, 39(8):4071–4090, August 1998.
- [69] J. Bertrand, P. Bertrand, and J. P. Ovarlez. "The Mellin transform". In A. D. Poularikas, editor, *The Transforms and Applications Handbook*, chapter 11, pages 829–885. CRC Press, Boca Raton, FL, 1st edition, 1996.
- [70] S. Bhashyam, A. M. Sayeed, and B. Aazhang. "Time-selective signaling and reception for communication over multipath fading channels". *IEEE Trans. Communications*, 48:83–94, January 2000.

- [71] B. Boashash. "Wigner analysis of time-varying signals—Its application in seismic prospecting". In *Proc. European Signal Processing Conf. (EUSIPCO-83)*, pages 703–706, Nürnberg, September 1983.
- [72] B. Boashash. "Note on the use of the Wigner distribution for time-frequency signal analysis". *IEEE Trans. Acoustics, Speech, & Signal Processing*, 36(9):1518–1521, September 1988.
- [73] B. Boashash. "Time-frequency signal analysis". In S. Haykin, editor, *Advances in Spectrum Analysis and Array Processing*, volume 1, chapter 9, pages 418–517. Prentice-Hall, Englewood Cliffs, NJ, 1991.
- [74] B. Boashash. "Estimating and interpreting the instantaneous frequency of a signal—Part 1: Fundamentals". *Proc. IEEE*, 80(4):520–538, April 1992.
- [75] B. Boashash. "Estimating and interpreting the instantaneous frequency of a signal—Part 1: Fundamentals; Part 2: Algorithms and applications". *Proc. IEEE*, 80(4):519–568, April 1992. With introductions by Michael J. Riezenman.
- [76] B. Boashash. "Estimating and interpreting the instantaneous frequency of a signal—Part 2: Algorithms and applications". *Proc. IEEE*, 80(4):540–568, April 1992.
- [77] B. Boashash, editor. Time-Frequency Signal Analysis: Methods and Applications. Longman-Cheshire/Wiley, Melbourne/N.Y., 1992.
- [78] B. Boashash. "Time-Frequency Signal Analysis: Past, present and future trends". In C. T. Leondes, editor, *Digital Control and Signal Processing Systems and Techniques*, number 78 in Control and Dynamic Systems: Advances in Theory and Applications, chapter 1, pages 1–69. Academic Press, San Diego, 1996.
- [79] B. Boashash, editor. Time-Frequency Signal Analysis and Processing: A Comprehensive Reference. Elsevier, Amsterdam, 2003.
- [80] B. Boashash and P. J. Black. "An efficient real-time implementation of the Wigner-Ville distribution". *IEEE Trans. Acoustics, Speech, & Signal Processing*, 35(11):1611–1618, November 1987.
- [81] B. Boashash and B. Escudie. "Wigner-Ville analysis of asymptotic signals and applications". Signal Processing, 8(3):315–327, June 1985.
- [82] B. Boashash and G. Frazer. "Time-varying higher-order spectra, generalised Wigner-Ville distribution and the analysis of underwater acoustic data". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'92)*, volume 5, pages 193–196, San Francisco, 23–26 March 1992.
- [83] B. Boashash, G. Jones, and P. J. O'Shea. "Instantaneous frequency of signals: Concepts, estimation techniques and applications". In *Proc. SPIE: Advanced Algorithms and Architectures for Signal Processing IV*, volume 1152, pages 382–400. Soc. of Photo-optical Instrumentation Engineers, San Diego, 8–10 August 1989.
- [84] B. Boashash and M. Mesbah. "A time-frequency approach for newborn seizure detection". *IEEE Engineering in Medicine & Biology Magazine*, 20(5):54–64, September/October 2001.
- [85] B. Boashash and M. Mesbah. "Time-frequency methodology for newborn EEG seizure detection". In A. Papandreou-Suppappola, editor, *Applications in Time-Frequency Signal Processing*, chapter 9. CRC Press, Boca Raton, FL, 2002.

- [86] B. Boashash and M. Mesbah. "Signal enhancement by time-frequency peak filtering". *IEEE Trans. Signal Processing*, 51(11), November 2003.
- [87] B. Boashash, M. Mesbah, and P. Colditz. "Newborn EEG seizure pattern characterisation using time-frequency analysis". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'01)*, volume 2, pages 1041–1044, Salt Lake City, UT, 7–11 May 2001.
- [88] B. Boashash and P. O'Shea. "Use of the cross Wigner-Ville distribution for estimation of instantaneous frequency". *IEEE Trans. Signal Processing*, 41(3):1439–1445, March 1993.
- [89] B. Boashash and P. J. O'Shea. "A methodology for detection and classification of some underwater acoustic signals using time-frequency analysis techniques". *IEEE Trans. Acoustics, Speech, & Signal Processing*, 38(11):1829–1841, November 1990.
- [90] B. Boashash and P. J. O'Shea. "Polynomial Wigner-Ville distributions and their relationship to time-varying higher order spectra". *IEEE Trans. Signal Processing*, 42(1):216–220, January 1994.
- [91] B. Boashash, P. J. O'Shea, and M. J. Arnold. "Algorithms for instantaneous frequency estimation: A comparative study". In *Proc. SPIE: Advanced Signal-Processing Algorithms, Architectures, and Implementations*, volume 1348, pages 126–148. Soc. of Photo-optical Instrumentation Engineers, San Diego, 10–12 July 1990.
- [92] B. Boashash and A. Reilly. "Algorithms for time-frequency signal analysis". In B. Boashash, editor, *Time-Frequency Signal Analysis: Methods and Applications*, chapter 7, pages 163–181. Longman-Cheshire/Wiley, Melbourne/N.Y., 1992.
- [93] B. Boashash and B. Ristic. "Analysis of FM signals affected by Gaussian AM using the reduced Wigner-Ville trispectrum". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'93)*, volume IV, pages 408–411, Minneapolis, 27–30 April 1993.
- [94] B. Boashash and B. Ristic. "A time-frequency perspective of higher-order spectra as a tool for non-stationary signal analysis". In B. Boashash, E. J. Powers, and A. M. Zoubir, editors, *Higher-Order Statistical Signal Processing*, chapter 4, pages 111–149. Longman/Wiley, Melbourne/N.Y., 1995.
- [95] B. Boashash and B. Ristic. "Polynomial time-frequency distributions and time-varying higher order spectra: Application to the analysis of multicomponent FM signal and to the treatment of multiplicative noise". Signal Processing, 67(1):1–23, May 1998.
- [96] B. Boashash and V. Sucic. "Resolution measure criteria for the objective assessment of the performance of quadratic time-frequency distributions". *IEEE Trans. Signal Processing*, 51(5):1253–1263, May 2003.
- [97] B. Boashash, L. B. White, and J. Imberger. "Wigner-Ville analysis of non-stationary random signals (with application to turbulent microstructure signals)". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'86)*, volume 4, pages 2323–2326, Tokyo, 7–11 April 1986.
- [98] B. Boashash and H. J. Whitehouse. "High resolution Wigner-Ville analysis". In *Eleventh GRETSI Symp. on Signal Processing and its Applications*, pages 205–208, Nice, France, 1–5 June 1987.

- [99] H. Bölcskei and F. Hlawatsch. "Oversampled modulated filter banks". In H. G. Feichtinger and T. Strohmer, editors, *Gabor Analysis and Algorithms: Theory and Applications*, chapter 9, pages 295–322. Birkhäuser, Berlin/Boston, 1998.
- [100] P. J. Boles and B. Boashash. "Application of the cross-Wigner-Ville distribution to seismic data processing". In B. Boashash, editor, *Time-Frequency Signal Analysis: Methods and Applications*, chapter 20, pages 445–466. Longman-Cheshire/Wiley, Melbourne/N.Y., 1992.
- [101] P. Bonato, P. Boissy, U. D. Croce, and S. H. Roy. "Changes in the surface EMG signal and the biomechanics of motion during a repetitive lifting task". *IEEE Trans. Neural System & Rehabilitation Engineering*, 10(1):38–47, March 2002.
- [102] M. Born and P. Jordan. "Zur quantenmechanik". Zeitschrift für Physik., 34:858–888, 1925.
- [103] G. F. Boudreaux-Bartels. Time-frequency signal processing algorithms: Analysis and synthesis using Wigner distribution. PhD thesis, Rice University, 1983.
- [104] G. F. Boudreaux-Bartels. "Mixed time-frequency signal transformations". In A. D. Poularikas, editor, *The Transforms and Applications Handbook*, chapter 12. CRC Press, Boca Raton, FL, 1st edition, 1996.
- [105] G. F. Boudreaux-Bartels and T. W. Parks. "Time-varying filtering and signal estimation using Wigner distribution synthesis techniques". *IEEE Trans. Acoustics, Speech, & Signal Processing*, 34(3):442–451, June 1986.
- [106] R. Bourdier, J. F. Allard, and K. Trumpf. "Effective frequency response and signal replica generation for filtering algorithms using multiplicative modifications of the STFT". Signal Processing, 15:193–201, September 1988.
- [107] T. Bülow and G. Sommer. "A novel approach to the 2D analytic signal". In F. Solina and A. Leonardis, editors, *Proc. 8th Internat. Conf. on Computer Analysis of Images & Patterns (CAIP'99)*, Ljubljana, Slovenia, 1–3 September 1999, number 1689 in LECTURE NOTES IN COMPUTER SCIENCE, pages 25–32. Springer, 1999.
- [108] A. Bultan. "A four-parameter atomic decomposition of chirplets". *IEEE Trans. Signal Processing*, 47(3):731–745, March 1999.
- [109] R. Burnett, J. F. Watson, and S. Elder. "The application of modern signal processing techniques for use in rotor fault detection and location within three-phase induction motors". Signal Processing, 49(1):57–70, February 1996.
- [110] A. B. Carlson. Communication Systems. McGraw-Hill, Tokyo, 2nd edition, 1975.
- [111] R. Carmona, W. L. Hwang, and B. Torrésani. Practical Time-Frequency Analysis: Gabor and Wavelet Transforms with an Implementation in S. Academic Press, San Diego, 1998.
- [112] W. G. Carrara, R. S. Goodman, and R. M. Majewski. Spotlight Synthetic Aperture Radar. Artech House, Norwood, MA, October 1995.
- [113] S. Carstens-Behrens, M. Wagner, and J. F. Böhme. "Detection of multiple resonances in noise". Archiv für Elektronik und Übertragungstechnik (Internat. J. of Electronics & Communications), 52(5):285–292, 1998.
- [114] P. Celka, B. Boashash, and P. Colditz. "Preprocessing and time-frequency analysis of newborn EEG seizures". *IEEE Engineering in Medicine & Biology Magazine*, 20(5):30–39, September/October 2001.

- [115] V. Chandran, S. Elgar, and A. Nguyen. "Detection of mines in acoustic images using higher order spectral features". *IEEE J. of Oceanic Engineering*, 27(3):610–618, July 2002.
- [116] E. Chassande-Mottin, F. Auger, and P. Flandrin. "Supervised time-frequency reassignment". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 517–520, Paris, 18–21 June 1996.
- [117] E. Chassande-Mottin, I. Daubechies, F. Auger, and P. Flandrin. "Differential reassignment". *IEEE Signal Processing Letters*, 4(10):293–294, October 1997.
- [118] E. Chassande-Mottin and P. Flandrin. "On the time-frequency detection of chirps". *Applied & Computational Harmonic Analysis*, 6(2):252–281, March 1999.
- [119] V. C. Chen and H. Ling. Time-Frequency Transforms for Radar Imaging and Signal Analysis. Scitech Publishing, 2002.
- [120] H.-I. Choi and W. J. Williams. "Improved time-frequency representation of multi-component signals using exponential kernels". *IEEE Trans. Acoustics, Speech, & Signal Processing*, 37(6):862–871, June 1989.
- [121] T. A. C. M. Claasen and W. F. G. Mecklenbräuker. "The Wigner Distribution—A tool for time-frequency signal analysis". *Philips J. of Research*, 35:217–250 (Part 1), 276–300 (Part 2) & 372–389 (Part 3), 1980.
- [122] T. A. C. M. Claasen and W. F. G. Mecklenbräuker. "The Wigner Distribution—A tool for time-frequency signal analysis; Part 1: Continuous-time signals". *Philips J. of Research*, 35(3):217–250, 1980.
- [123] T. A. C. M. Claasen and W. F. G. Mecklenbräuker. "The Wigner Distribution—A tool for time-frequency signal analysis; Part 3: Relations with other time-frequency signal transformations". *Philips J. of Research*, 35(6):372–389, 1980.
- [124] M. Coates and W. J. Fitzgerald. "Time-frequency signal decomposition using energy mixture models". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP 2000)*, volume 2, pages 633–636, Istanbul, 5–9 June 2000.
- [125] F. S. Cohen, S. Kadambe, and G. F. Boudreaux-Bartels. "Tracking of unknown non-stationary chirp signals using unsupervised clustering in the Wigner distribution space". *IEEE Trans. Signal Processing*, 41(11):3085–3101, November 1993.
- [126] L. Cohen. "Generalized phase-space distribution functions". J. of Mathematical Physics, 7(5):781–786, May 1966.
- [127] L. Cohen. "Time-frequency distributions—A review". *Proc. IEEE*, 77(7):941–981, July 1989. Invited paper.
- [128] L. Cohen. "Distributions concentrated along the instantaneous frequency". In *Proc. SPIE: Advanced Signal-Processing Algorithms, Architectures, and Implementations*, volume 1348, pages 149–157. Soc. of Photo-optical Instrumentation Engineers, San Diego, 10–12 July 1990.
- [129] L. Cohen. "Introduction: A primer on time-frequency analysis". In B. Boashash, editor, *Time-Frequency Signal Analysis: Methods and Applications*, chapter 1, pages 3–42. Longman-Cheshire/Wiley, Melbourne/N.Y., 1992.
- [130] L. Cohen. "The scale representation". *IEEE Trans. Signal Processing*, 41(12):3275–3292, December 1993.

- [131] L. Cohen. Time-Frequency Analysis. Prentice-Hall, Englewood Cliffs, NJ, 1995.
- [132] L. Cohen. "Wavelet moments and time-frequency analysis". In *Proc. SPIE: Advanced Signal Processing Algorithms, Architectures, and Implementations IX*, volume 3807, pages 434–445. Soc. of Photo-optical Instrumentation Engineers, Denver, CO, 19–21 July 1999.
- [133] A. H. Costa and G. F. Boudreax-Bartels. "An overview of aliasing errors in discrete-time formulations of time-frequency distributions". *IEEE Trans. Signal Processing*, 47(5):1463–1474, May 1999.
- [134] H. Cox. "Line array performance when the signal coherence is spatially dependent". J. Acoustical Soc. of America, 54:1743–1746, July 1973.
- [135] G. Cristóbal, J. Bescós, and J. Santamaría. "Image analysis through the Wigner distribution function". *Applied Optics*, 28(2):262–271, January 1989.
- [136] G. Cristóbal and J. Hormigo. "Texture segmentation through eigen-analysis of the Pseudo-Wigner distribution". *Pattern Recognition Letters*, 20:337–345, 1999.
- [137] G. S. Cunningham and W. J. Williams. "Fast implementations of generalized discrete time-frequency distributions". *IEEE Trans. Signal Processing*, 42(6):1496–1508, June 1994.
- [138] G. S. Cunningham and W. J. Williams. "Kernel decomposition of time-frequency distributions". *IEEE Trans. Signal Processing*, 42(6):1425–1442, June 1994.
- [139] R. N. Czerwinski and D. L. Jones. "Adaptive cone-kernel time-frequency analysis". *IEEE Trans. Signal Processing*, 43(7):1715–1719, July 1995.
- [140] I. Daubechies. "Time-frequency localization operators: A geometric phase space approach". IEEE Trans. Information Theory, 34:605–612, July 1988.
- [141] I. Daubechies. "The wavelet transform, time-frequency localization and signal analysis". *IEEE Trans. Information Theory*, 36(5):961–1005, September 1990.
- [142] I. Daubechies. "The wavelet transform: A method for time-frequency localization". In S. Haykin, editor, *Advances in Spectrum Analysis and Array Processing*, volume 1, chapter 8, pages 366–417. Prentice-Hall, Englewood Cliffs, NJ, 1991.
- [143] M. Davy, C. Doncarli, and G. F. Boudreaux-Bartels. "Improved optimization of time-frequency-based signal classifiers". *IEEE Signal Processing Letters*, 8(2):52–57, February 2001.
- [144] M. Davy and A. Doucet. "Copulas: A new insight into positive time-frequency distributions". *IEEE Signal Processing Letters*, 10(7):215–218, July 2003.
- [145] N. G. de Bruijn. "A theory of generalized functions, with applications to Wigner distribution and Weyl correspondence". *Nieuw Archief voor Wiskunde* (3), 21:205–280, 1073
- [146] S. R. Deans. "Radon and Abel transforms". In A. D. Poularikas, editor, The Transforms and Applications Handbook, chapter 8. CRC Press, Boca Raton, FL, 1st edition, 1996.
- [147] C. S. Detka and A. El-Jaroudi. "The transitory evolutionary spectrum". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'94)*, volume 4, pages 289–292, Adelaide, Australia, 19–22 April 1994.
- [148] I. Djurović, V. Katkovnik, and L. Stanković. "Median filter based realizations of the robust time-frequency distributions". Signal Processing, 81(8):1771–1776, August 2001.

- [149] I. Djurović and L. Stanković. "Influence of high noise on the instantaneous frequency estimation using quadratic time-frequency distributions". *IEEE Signal Processing Letters*, 7(11):317–319, November 2000.
- [150] I. Djurović and L. Stanković. "Robust Wigner distribution with application to the instantaneous frequency estimation". *IEEE Trans. Signal Processing*, 49(12):2985–2993, December 2001.
- [151] I. Djurović, L. Stanković, and J. F. Böhme. "Estimates of the Wigner distribution in Gaussian noise environment". Archiv für Elektronik und Übertragungstechnik (Internat. J. of Electronics & Communications), 56(5):337–340, 2002.
- [152] I. Djurović and S. Stanković. "Estimation of time-varying velocities of moving objects by time-frequency representations". *IEEE Trans. Image Processing*, 12(5):550–562, May 2003.
- [153] R. Du. "Engineering monitoring and diagnosis using wavelet transforms". In C. T. Leondes, editor, Computer-Aided Design, Engineering, and Manufacturing: Systems Techniques and Applications—Vol. I: Systems Techniques and Computational Methods, chapter 8. CRC Press, 2000.
- [154] P. Duvaut and D. Declerq. "Statistical properties of the pseudo-Wigner-Ville representation of normal random processes". Signal Processing, 75(1):93–98, 5 January 1999.
- [155] G. Eichmann and N. M. Marinovich. "Scale-invariant Wigner distribution". In Proc. SPIE: Analog Optical Processing and Computing, volume 519, pages 18–25. Soc. of Photo-optical Instrumentation Engineers, Cambridge, MA, 25–26 October 1984.
- [156] S. El-Khamy, S. E. Shaaban, and E. A. Thabet. "Frequency-hopped multi-user chirp modulation (FH/M-CM) for multipath fading channels". In *Proc. Sixteenth National Radio Science Conference (NRSC'99)*, pages C6/1–8, Ain Shams Univ., Cairo, 23–25 February 1999.
- [157] M. K. Emresoy and A. El-Jaroudi. "Iterative instantaneous frequency estimation and adaptive matched spectrogram". Signal Processing, 64(2):157–65, January 1998.
- [158] S. Farkash and S. Raz. "Linear systems in Gabor time-frequency space". $\it IEEE Trans. Signal Processing, 42(3):611–617, March 1994.$
- [159] H. G. Feichtinger and T. Strohmer, editors. *Gabor Analysis and Algorithms: Theory and Applications*. Birkhäuser, Berlin/Boston, 1998.
- [160] H. G. Feichtinger and T. Strohmer. Advances in Gabor Analysis. Birkhaüser, 2002.
- [161] B. Ferguson. "A ground based narrow-band passive acoustic technique for estimating the altitude and speed of a propeller driven aircraft". J. Acoustical Soc. of America, 92(3):1403–1407, September 1992.
- [162] B. G. Ferguson. "Time-frequency signal analysis of hydrophone data". *IEEE J. of Oceanic Engineering*, 21(4):537–544, October 1996.
- [163] B. G. Ferguson and K. W. Lo. "Transiting aircraft parameter estimation using underwater acoustic sensor data". *IEEE J. of Oceanic Engineering*, 24(4):424–435, October 1999.
- [164] B. G. Ferguson and B. G. Quinn. "Application of the short-time Fourier transform and the Wigner-Ville distribution to the acoustic localization of aircraft". J. Acoustical Soc. of America, 96:821–827, 1994.

- [165] A. C. A. Figueiredo and J. P. S. Bizarro. "Time-frequency images of magnetohydrodynamic phenomena in tokamak plasmas using a discrete-time Wigner distribution". *IEEE Trans. Plasma Science*, 30(1):54–55, February 2002.
- [166] P. Flandrin. "Some features of time-frequency representations of multicomponent signals". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'84)*, volume 3, pages 41B.4.1–41B.4.4, San Diego, 19–21 March 1984.
- [167] P. Flandrin. "A time-frequency formulation of optimum detection". *IEEE Trans. Acoustics, Speech, & Signal Processing*, 36(9):1377–1384, September 1988.
- [168] P. Flandrin. "Time-dependent spectra for nonstationary stochastic processes". In G. Longo and B. Picinbono, editors, *Time and Frequency Representation of Signals and Systems*, pages 69–124. Springer, Vienna, 1989.
- [169] P. Flandrin. *Time-Frequency/Time-Scale Analysis*. Academic Press, San Diego, 1999. Original French edition: *Temps-fréquence* (Paris: Hermès, 1993).
- [170] P. Flandrin, R. G. Baraniuk, and O. Michel. "Time-frequency complexity and information". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'94)*, volume 3, pages 329–332, Adelaide, Australia, 19–22 April 1994.
- [171] P. Flandrin, E. Chassande-Mottin, and P. Abry. "Reassigned scalograms and their fast algorithms". In *Proc. SPIE: Wavelet Applications in Signal and Image Processing III*, volume 2569, pages 152–158. Soc. of Photo-optical Instrumentation Engineers, San Diego, CA, 12–14 July 1995.
- [172] P. Flandrin and P. Gonçalvès. "Geometry of affine time-frequency distributions". *Applied & Computational Harmonic Analysis*, 3:10–39, January 1996.
- [173] P. Flandrin and W. Martin. "The Wigner-Ville spectrum of nonstationary random signals". In W. Mecklenbräuker and F. Hlawatsch, editors, *The Wigner Distribution*—

 Theory and Applications in Signal Processing, pages 211–267. Elsevier, Amsterdam, 1997.
- [174] G. B. Folland. Harmonic Analysis in Phase Space. Number 122 in Annals of Mathematics Studies. Princeton University Press, Princeton, NJ, 1989.
- [175] B. D. Forrester. "Time-frequency analysis in machine fault detection". In B. Boashash, editor, *Time-Frequency Signal Analysis: Methods and Applications*, chapter 18, pages 406–423. Longman-Cheshire/Wiley, Melbourne/N.Y., 1992.
- [176] W. L. J. Fox, J. C. Luby, J. W. Pitton, P. J. Loughlin, and L. E. Atlas. "Sonar and radar range-Doppler processing using a cone-shaped kernel time-frequency representation". In *Proc. 24th Asilomar Conf. on Signals, Systems, and Computers*, volume 2, pages 1079–1083, Pacific Grove, CA, 5–7 November 1990.
- [177] G. J. Frazer and B. Boashash. "Multiple window spectrogram and time-frequency distributions". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'94)*, volume IV, pages 293–296, Adelaide, Australia, 19–22 April 1994.
- [178] D. Friedman. "Instantaneous frequency distribution vs. time: An interpretation of the phase structure of speech". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'85)*, pages 1121–1124, Tampa, FL, 26–29 March 1985.
- [179] D. Gabor. "Theory of communication". J. IEE, 93(III)(26):429-457, November 1946.
- [180] R. G. Gallager. Information Theory and Reliable Communication. Wiley, New York, 1968.

- [181] M. A. García-Pérez and V. Sierra-Vázquez. "Visual processing in the joint spatial/spatial-frequency domain". In E. Peli, editor, *Vision Models for Target Detection and Recognition: In Memory of Arthur Menendez*, chapter 2, pages 16–62. World Scientific Publishing, 1995.
- [182] W. A. Gardner, editor. Cyclostationarity in Communications and Signal Processing. IEEE Press, Piscataway, NJ, 1995.
- [183] N. L. Gerr. "Introducing a third-order Wigner distribution". *Proc. IEEE*, 76(3):290–292, March 1988.
- [184] A. B. Gershman and M. G. Amin. "Wideband direction-of-arrival estimation of multiple chirp signals using spatial time-frequency distributions". *IEEE Signal Processing Letters*, 7(6):152–155, June 2000.
- [185] A. B. Gershman, L. Stanković, and V. Katkovnik. "Sensor array signal tracking using a data-driven window approach". *Signal Processing*, 80(12):2507–2515, December 2000.
- [186] A. Gersho and R. M. Gray. Vector Quantization and Signal Compression. Kluwer, 1991.
- [187] S. Ghaemmaghami, M. Deriche, and B. Boashash. "Hierarchical approach to formant detection and tracking through instantaneous frequency estimation". *IEE Electronics Letters*, 33(1):17–18, January 1997.
- [188] S. C. Glinski. "Diphone speech synthesis based on a pitch-adaptive short-time Fourier transform". Master's thesis, Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, 1981.
- [189] G. H. Golub and C. F. Van Loan. *Matrix computations*. Johns Hopkins University Press, Baltimore, MD, 1989.
- [190] P. Gonçalvès and R. G. Baraniuk. "Pseudo affine Wigner distributions: Definition and kernel formulation". *IEEE Trans. Signal Processing*, 46(6):1505–1517, June 1998.
- [191] E. Grall-Maes and P. Beauseroy. "Mutual information-based feature extraction on the time-frequency plane". *IEEE Trans. Signal Processing*, 50(4):779–790, April 2002.
- [192] S. Gu, J. Ni, and J. Yuan. "Non-stationary signal analysis and transient machining process condition monitoring". *Internat. J. Machine Tools & Manufacture*, 42(1):41–51, January 2002.
- [193] P. Guillemain and R. Kronland-Martinet. "Horizontal and vertical ridges associated to continuous wavelet transforms". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 63–66, Victoria, BC, 4–6 October 1992.
- [194] C. Gupta and A. Papandreou-Suppappola. "Wireless CDMA communications using time-varying signals". In *Proc. Sixth Internat. Symp. on Signal Processing and its Applications (ISSPA'01)*, volume 1, pages 242–245, Kuala Lumpur, 13–16 August 2001.
- [195] S. L. Hahn. "Multidimensional complex signals with single-orthant spectra". Proc. IEEE, 80(8):1287-1300, August 1992.
- [196] S. L. Hahn and K. M. Snopek. "Double-dimensional distributions: Another approach to "quartic" distributions". *IEEE Trans. Signal Processing*, 50(12):2987–2997, December 2002.

- [197] A. Hanssen and L. L. Scharf. "A theory of polyspectra for nonstationary stochastic processes". *IEEE Trans. Signal Processing*, 51(5):1243–1252, May 2003.
- [198] H. Hassanpour, M. Mesbah, and B. Boashash. "Comparative performance of time-frequency based newborn EEG seizure detection using spike signatures". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'03)*, volume 2, pages 389–392, Hong Kong, scheduled 6–10 April 2003.
- [199] S. B. Hearon and M. G. Amin. "Minimum-variance time-frequency distribution kernels". *IEEE Trans. Signal Processing*, 43(5):1258–1262, May 1995.
- [200] C. E. Heil and D. F. Walnut. "Continuous and discrete wavelet transforms". SIAM Review, 31(4):628–666, December 1989.
- [201] C. W. Helstrom. "An expansion of a signal in Gaussian elementary signals". *IEEE Trans. Information Theory*, 12:81–82, January 1966.
- [202] C. W. Helstrom. The Statistical Theory of Signal Detection. Oxford University Press, New York, 1968.
- [203] F. B. Hildebrand. Advanced Calculus for Engineers. Prentice-Hall, New York, 1949.
- [204] J. Hilgevoord and J. Uffink. "The mathematical expression of the uncertainty principle". In A. van der Merwe, G. Tarozzi, and F. Selleri, editors, *Microphysical Reality and Quantum Formalism*, number 25–26 in Fundamental Theories of Physics, pages 91–114. Kluwer, Dordrecht, 1988. Proc. of the Conf. at Urbino, Italy, 25 Sep. to 3 Oct., 1985.
- [205] F. Hlawatsch. "Interference terms in the Wigner distribution". In *Proc. Internat. Conf. on Digital Signal Processing*, pages 363–367, Florence, Italy, 5–8 September 1984.
- [206] F. Hlawatsch. Time-Frequency Analysis and Synthesis of Linear Signal Spaces: Time-Frequency Filters, Signal Detection and Estimation, and Range-Doppler Estimation. Kluwer, Boston, 1998.
- [207] F. Hlawatsch and H. Bölcskei. "Unified theory of displacement-covariant time-frequency analysis". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 524–527, Philadelphia, PA, 25–28 October 1994.
- [208] F. Hlawatsch and G. F. Boudreaux-Bartels. "Linear and quadratic time-frequency signal representations". *IEEE Signal Processing Magazine*, 9(2):21–67, April 1992.
- [209] F. Hlawatsch and P. Flandrin. "The interference structure of the Wigner distribution and related time-frequency signal representations". In W. Mecklenbräuker and F. Hlawatsch, editors, *The Wigner Distribution—Theory and Applications in Signal Processing*, pages 59–133. Elsevier, Amsterdam, 1997.
- [210] F. Hlawatsch and G. Matz. "Quadratic time-frequency analysis of linear time-varying systems". In L. Debnath, editor, Wavelet Transforms and Time-Frequency Signal Analysis, chapter 9, pages 235–287. Birkhäuser, Boston, 2001.
- [211] F. Hlawatsch, G. Matz, H. Kirchauer, and W. Kozek. "Time-frequency formulation, design, and implementation of time-varying optimal filters for signal estimation". *IEEE Trans. Signal Processing*, 48(5):1417–1432, May 2000.
- [212] F. Hlawatsch, A. Papandreou-Suppappola, and G. F. Boudreaux-Bartels. "The hyperbolic class of quadratic time-frequency representations—Part II: Subclasses, intersection with the affine and power classes, regularity, and unitarity". *IEEE Trans. Signal Processing*, 45(2):303–315, February 1997.

- [213] F. Hlawatsch, A. Papandreou-Suppappola, and G. F. Boudreaux-Bartels. "The power classes—Quadratic time-frequency representations with scale covariance and dispersive time-shift covariance". *IEEE Trans. Signal Processing*, 47(11):3067–3083, November 1999.
- [214] F. Hlawatsch, G. Tauböck, and T. Twaroch. "Covariant time-frequency analysis". In L. Debnath, editor, Wavelets and Signal Processing. Birkhäuser, Boston, 2003.
- [215] F. Hlawatsch and T. Twaroch. "Covariant (α, β) , time-frequency, and (a, b) representations". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 437–440, Paris, 18–21 June 1996.
- [216] F. Hlawatsch and R. L. Urbanke. "Bilinear time-frequency representations of signals: The shift-scale invariant class". *IEEE Trans. Signal Processing*, 42:357–366, 1994.
- [217] J. Hormigo and G. Cristóbal. "High resolution spectral analysis of images using the pseudo-Wigner distribution". *IEEE Trans. Signal Processing*, 46(6):1757–1763, June 1998.
- [218] C. Hory, N. Martin, and A. Chehikian. "Spectrogram segmentation by means of statistical features for non-stationary signal interpretation". *IEEE Trans. Signal Processing*, 50(12):2915–2925, December 2002.
- [219] Y. Hu, K. D. Luk, W. W. Lu, and J. C. Leong. "Comparison of time-frequency analysis techniques in intraoperative somatosensory evoked potential (SEP) monitoring". Computers in Biology & Medicine, 32(1):13–23, January 2002.
- [220] P. J. Huber. Robust statistics. Wiley, 1981.
- [221] Z. M. Hussain and B. Boashash. "Adaptive instantaneous frequency estimation of multicomponent FM signals". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP 2000)*, volume II, pages 657–660, Istanbul, 5–9 June 2000.
- [222] Z. M. Hussain and B. Boashash. "Multi-component IF estimation". In *Proc. Tenth IEEE Workshop on Statistical Signal and Array Processing (SSAP-2000)*, pages 559–563, Pocono Manor, PA, 14–16 August 2000.
- [223] Z. M. Hussain and B. Boashash. "Design of time-frequency distributions for amplitude and IF estimation of multicomponent signals". In *Proc. Sixth Internat. Symp. on Signal Processing and its Applications (ISSPA'01)*, volume 1, pages 339–342, Kuala Lumpur, 13–16 August 2001.
- [224] Z. M. Hussain and B. Boashash. "Adaptive instantaneous frequency estimation of multicomponent FM signals using quadratic time-frequency distributions". *IEEE Trans. Signal Processing*, 50(8):1866–1876, August 2002.
- [225] Q. Q. Huynh, L. N. Cooper, N. Intrator, and H. Shouval. "Classification of underwater mammals using feature extraction based on time-frequency analysis and BCM theory". *IEEE Trans. Signal Processing*, 46(5):1202–1207, May 1998.
- [226] B. G. Iem, A. Papandreou-Suppappola, and G. F. Boudreaux-Bartels. "New concepts in narrowband and wideband Weyl correspondence time-frequency techniques". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'98)*, volume 3, pages 1573–1576, Seattle, 12–15 May 1998.
- [227] B. G. Iem, A. Papandreou-Suppappola, and G. F. Boudreaux-Bartels. "A wideband time-frequency Weyl symbol and its generalization". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 29–32, Pittsburgh, PA, 6–9 October 1998.

- [228] B. G. Iem, A. Papandreou-Suppappola, and G. F. Boudreaux-Bartels. "Classes of smoothed Weyl symbols". *IEEE Signal Processing Letters*, 7(7):186–188, July 2000.
- [229] J. Imberger and B. Boashash. "Application of the Wigner-Ville distribution to temperature gradient microstructure: A new technique to study small-scale variations". J. of Physical Oceanography, 16:1997–2012, December 1986.
- [230] L. Jacobson and H. Wechsler. "Joint spatial/spatial-frequency representation". Signal Processing, 14:37–68, 1988.
- [231] J. S. Jaffe, G. Chandran, and E. Reuss. "High frequency acoustic imaging in the ocean". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'95)*, volume 5, pages 2793–2796, Detroit, 9–12 May 1995.
- [232] A. Jakobsson, S. L. Marple Jr., and P. Stoica. "Computationally efficient two-dimensional Capon spectrum analysis". *IEEE Trans. Signal Processing*, 48(9):2651–2661, September 2000.
- [233] J. Jeong and W. J. Williams. "Alias-free generalised discrete-time time-frequency distributions". *IEEE Trans. Signal Processing*, 40(11):2757–2765, November 1992.
- [234] J. Jeong and W. J. Williams. "Kernel design for reduced interference distributions". *IEEE Trans. Signal Processing*, 40(2):402–412, February 1992.
- [235] D. L. Jones and R. G. Baraniuk. "A simple scheme for adapting time-frequency representations". *IEEE Trans. Signal Processing*, 42(12):3530–3535, December 1994.
- [236] D. L. Jones and R. G. Baraniuk. "Adaptive optimal-kernel time-frequency representation". *IEEE Trans. Signal Processing*, 43(10):2361–2371, October 1995.
- [237] D. L. Jones and T. W. Parks. "A high-resolution data-adaptive time-frequency representation". *IEEE Trans. Acoustics, Speech, & Signal Processing*, 38(12):2127–2135, December 1990.
- [238] D. L. Jones and T. W. Parks. "A resolution comparison of several time-frequency representations". *IEEE Trans. Signal Processing*, 40(2):413–420, February 1992.
- [239] G. Jones and B. Boashash. "Generalized instantaneous parameters and window matching in the time-frequency plane". *IEEE Trans. Signal Processing*, 45(5):1264–1275, May 1997.
- [240] S. M. Joshi and J. M. Morris. "Some results on product-function frames". *Signal Processing*, 80(4):737–740, April 2000.
- [241] S. Kadambe and T. Adali. "Application of cross-term deleted Wigner representation (CDWR) for sonar target detection/classification". In *Proc. 32nd Asilomar Conf. on Signals, Systems, and Computers*, volume 1, pages 822–826, Pacific Grove, CA, 1–4 November 1998.
- [242] T. A. Kadous and A. M. Sayeed. "Decentralized multiuser detection for time-varying multipath channels". *IEEE Trans. Communications*, 48:1840–1852, November 2000.
- [243] M. H. Kahaei, A. M. Zoubir, B. Boashash, and M. Deriche. "Tracking behaviour of lattice filters for linear and quadratic FM signals". In Wysocki et al. [506], pages 207–214.
- [244] S. A. Kassam. Signal detection in non-Gaussian noise. Springer, 1988.
- [245] S. A. Kassam and H. V. Poor. "Robust techniques for signal processing: A survey". Proc. IEEE, 73(3):433–481, March 1985.

- [246] V. Katkovnik. "Robust M-periodogram". *IEEE Trans. Signal Processing*, 46(11):3104–3109, November 1998.
- [247] V. Katkovnik. "Robust M-estimates of the frequency and amplitude of a complex-valued harmonic". $Signal\ Processing,\ 77(1):71-84,\ August\ 1999.$
- [248] V. Katkovnik and L. Stanković. "Instantaneous frequency estimation using the Wigner distribution with varying and data-driven window length". *IEEE Trans. Signal Processing*, 46(9):2315–2325, September 1998.
- [249] V. Katkovnik and L. Stanković. "Periodogram with varying and data-driven window length". Signal Processing, 67(3):345–358, 30 June 1998.
- [250] J. Kay and R. Lerner. Lectures in Communications Theory. McGraw-Hill, 1961.
- [251] A. S. Kayhan and M. G. Amin. "Spatial evolutionary spectrum for DOA estimation and blind signal separation". *IEEE Trans. Signal Processing*, 48(3):791–798, March 2000.
- [252] E. J. Kelly and R. P. Wishner. "Matched filter theory for high-velocity, accelerating targets". *IEEE Trans. Military Electronics*, 9:56–59, 1965.
- [253] R. S. Kennedy. Fading dispersive communication channels. Wiley, New York, 1969.
- [254] O. P. Kenny and B. Boashash. "Time-frequency analysis of backscattered signals from diffuse radar targets". *IEE Proc.*, Part F: Radar & Signal Processing, 140(3):198–208, June 1993.
- [255] H. A. Khan and L. F. Chaparro. "Nonstationary Wiener filtering based on evolutionary spectral theory". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'97)*, volume 5, pages 3677–3680, Munich, 21–24 April 1997.
- [256] H. Kirchauer, F. Hlawatsch, and W. Kozek. "Time-frequency formulation and design of nonstationary Wiener filters". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'95)*, pages 1549–1552, Detroit, 9–12 May 1995.
- [257] J. G. Kirkwood. "Quantum statistics of almost classical ensembles". *Physics Review*, 44:31–37, 1933.
- [258] L. Knockaert. "A class of positive isentropic time-frequency distributions". *IEEE Signal Processing Letters*, 9(1):22–25, January 2002.
- [259] K. Kodera, C. de Villedary, and R. Gendrin. "A new method for the numerical analysis of nonstationary signals". *Physics of the Earth & Planetary Interiors*, 12:142–150, 1976.
- [260] W. Koenig, H. K. Dunn, and L. Y. Lacy. "The sound spectrograph". J. Acoustical Soc. of America, 18(1):19–49, 1946.
- [261] D. König. "Application of time-frequency analysis for optimum non-equidistant sampling of automotive signals captured at knock". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'96)*, volume 5, pages 2746–2749, Atlanta, GA, 7–10 May 1996.
- [262] P. J. Kootsookos, B. C. Lovell, and B. Boashash. "A unified approach to the STFT, TFDs, and instantaneous frequency". *IEEE Trans. Signal Processing*, 40(8):1971–82, August 1992.
- [263] W. Kozek. "On the generalized Weyl correspondence and its application to time-frequency analysis of linear time-varying systems". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 167–170, Victoria, BC, 4–6 October 1992.

- [264] W. Kozek. "Time-frequency signal processing based on the Wigner-Weyl framework". Signal Processing, 29(1):77–92, October 1992.
- [265] W. Kozek. "On the transfer function calculus for underspread LTV channels". *IEEE Trans. Signal Processing*, 45(1):219–223, January 1997.
- [266] W. Kozek, H. G. Feichtinger, and J. Scharinger. "Matched multiwindow methods for the estimation and filtering of nonstationary processes". In *Proc. IEEE Internat. Symp. on Circuits and Systems (ISCAS 96)*, volume 2, pages 509–512, Atlanta, GA, 12–15 May 1996
- [267] W. Kozek and F. Hlawatsch. "A comparative study of linear and nonlinear time-frequency filters". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 163–166, Victoria, BC, 4–6 October 1992.
- [268] W. Kozek, F. Hlawatsch, H. Kirchauer, and U. Trautwein. "Correlative time-frequency analysis and classification of nonstationary random processes". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 417–420, Philadelphia, PA, 25–28 October 1994.
- [269] W. Kozek and A. F. Molisch. "On the eigenstructure of underspread WSSUS channels". In *Proc. IEEE-SP Workshop on Signal Processing Advances in Wireless Communications (SPAWC'97)*, pages 325–328, Paris, 16–18 April 1997.
- [270] W. Kozek and A. F. Molisch. "Nonorthogonal pulseshapes for multicarrier communications in doubly dispersive channels". *IEEE J. on Selected Areas in Communications*, 16:1579–1589, October 1998.
- [271] S. Krishnamachari and W. J. Williams. "Adaptive kernel design in the generalized marginals domain for time-frequency analysis". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'94)*, volume 3, pages 341–344, Adelaide, Australia, 19–22 April 1994.
- [272] S. R. Kulkarni, G. Lugosi, and S. S. Venkatesh. "Learning pattern classification—A survey". *IEEE Trans. Information Theory*, 44(6):2178–2206, October 1998.
- [273] R. Kumaresan and S. Verma. "On estimating the parameters of chirp signals using rank reduction techniques". In *Proc. 21st Asilomar Conf. on Signals, Systems, and Computers*, pages 555–558, Pacific Grove, CA, 2–4 November 1987.
- [274] S. Lach, M. G. Amin, and A. R. Lindsey. "Broadband nonstationary interference excision in spread-spectrum communications using time-frequency synthesis techniques". *IEEE J. on Selected Areas in Communications*, 17(4):704–714, April 1999.
- [275] F. Lari and A. Zakhor. "Automatic classification of active sonar data using time-frequency transforms". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 21–24, Victoria, BC, 4-6 October 1992.
- [276] S. K. Lee and P. R. White. "Higher-order time-frequency analysis and its application to fault detection in rotating machinery". *J. Mechanical Systems and Signal Processing*, 11(4):637–650, July 1997.
- [277] M. J. Levin. "Instantaneous spectra and ambiguity functions". *IEEE Trans. Information Theory*, 10:95–97, January 1964.
- [278] A. R. Leyman, Z. M. Kamran, and K. Abed-Meraim. "Higher-order time frequency-based blind source separation technique". *IEEE Signal Processing Letters*, 7(7):193–196, July 2000.

- [279] S. Li and D. M. Healy, Jr. "A parametric class of discrete Gabor expansions". *IEEE Trans. Signal Processing*, 44(2):201–211, February 1996.
- [280] E. H. Lieb. "Integral bounds for radar ambiguity functions and Wigner distributions". J. of Mathematical Physics, 31(3):594–599, March 1990.
- [281] J. S. Lim and A. V. Oppenheim. "Enhancement and bandwidth compression of noisy speech". *Proc. IEEE*, 67(12):1586–1604, December 1979.
- [282] N. Linh-Trung, A. Belouchrani, K. Abed-Meraim, and B. Boashash. "Separating more sources than sensors using time-frequency distributions". In *Proc. Sixth Internat. Symp. on Signal Processing and its Applications (ISSPA'01)*, volume 2, pages 583–586, Kuala Lumpur, 13–16 August 2001.
- [283] K. W. Lo and B. G. Ferguson. "Passive estimation of aircraft motion parameters using destructive interference between direct and ground-reflected sound waves". In *Proc. Information Decision & Control 99*, pages 171–176. IEEE, Adelaide, Australia, February 1999.
- [284] K. W. Lo, S. W. Perry, and B. G. Ferguson. "Aircraft flight parameter estimation using acoustical Lloyd's mirror effect". *IEEE Trans. Aerospace & Electronic Systems*, 38(1):137–151, January 2002.
- [285] A. W. Lohmann, D. Mendlovic, and Z. Zalevsky. "Fractional transformations in optics". In E. Wolf, editor, *Progress in Optics—Vol. 38*, chapter 4, pages 263–342. Elsevier, Amsterdam, 1998.
- [286] A. W. Lohmann and B. H. Soffer. "Relationships between the Radon-Wigner and fractional Fourier transforms". J. Optical Soc. of America A, 11(6):1798–1801, June 1994.
- [287] C. T. Lombroso. "Neonatal EEG polygraphy in normal and abnormal newborns". In E. Niedermeyer and F. H. Lopes da Silva, editors, *Electroencephalography: Basic Principles, Clinical Applications, and Related Fields*, pages 803–875. Williams & Wilkins, Baltimore, MD, 3rd edition, 1993.
- [288] P. Loughlin and B. Tacer. "On the amplitude and frequency-modulation decomposition of signals". *J. Acoustical Soc. of America*, 100:1594–1601, September 1996.
- [289] P. J. Loughlin, J. W. Pitton, and L. E. Atlas. "Bilinear time-frequency representations: New insights and properties". *IEEE Trans. Signal Processing*, 41:750–767, 1993.
- [290] J. G. Lourens. "Passive sonar detection of ships with spectro-grams". In Proc. 3rd South African IEEE Conference on Theoretical and Practical Work in Communications and Signal Processing, pages 147–151, Johannesburg, June 1990.
- [291] B. Lovell, R. C. Williamson, and B. Boashash. "The relationship between instantaneous frequency and time-frequency representations". *IEEE Trans. Signal Processing*, 41(3):1458–1461, March 1993.
- [292] N. Ma, D. Vray, P. Delachartre, and G. Gimenez. "Sea-bottom backscattering modeling with a wideband constant beamwidth sonar at normal incidence". In *Proc. IEEE Ultrasonics Symposium*, volume 2, pages 1077–1080, Seattle, 7–10 November 1995.
- [293] S. Maes. "The synchrosqueezed representation yields a new reading of the wavelet transform". In *Proc. SPIE: Wavelet Applications II*, volume 2491, pages 532–559. Soc. of Photo-optical Instrumentation Engineers, Orlando, FL, 17–21 April 1995.

- [294] I. Magrin-Chagnolleau, G. Durou, and F. Bimbot. "Application of time-frequency principal component analysis to text-independent speaker identification". *IEEE Trans. on Speech & Audio Processing*, 10(6):371–378, September 2002.
- [295] S. G. Mallat. A Wavelet Tour of Signal Processing. Academic Press, San Diego, 1st edition, 1998.
- [296] S. G. Mallat. A Wavelet Tour of Signal Processing. Academic Press, San Diego / London, 2nd edition, 1999.
- [297] S. G. Mallat and Z. Zhang. "Matching pursuits with time-frequency dictionaries". *IEEE Trans. Signal Processing*, 41(12):3397–3415, December 1993.
- [298] H. Margenau and R. N. Hill. "Correlation between measurements in quantum theory". *Progress of Theoretical Physics*, 26:722–738, 1961.
- [299] S. L. Marple Jr. Digital Spectral Analysis with Applications. Prentice-Hall, Englewood Cliffs, NJ, 1987.
- [300] S. L. Marple Jr. "Computing the discrete-time "analytic" signal via FFT". *IEEE Trans. Signal Processing*, 47(9):2600–2603, September 1999.
- [301] S. L. Marple Jr. "Two-dimensional lattice linear prediction parameter estimation method and fast algorithm". *IEEE Signal Processing Letters*, 7(6):164–168, June 2000.
- [302] S. L. Marple Jr. and T. Brotherton. "Detection and classification of short duration underwater acoustic signals by Prony's method". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'91)*, volume 2, pages 1309–1312, Toronto, 14–17 May 1991.
- [303] W. Martin. "Time-frequency analysis of random signals". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'82)*, volume 3, pages 1325–1328, Paris, 3–5 May 1982.
- [304] W. Martin and P. Flandrin. "Wigner-Ville spectral analysis of nonstationary processes". *IEEE Trans. Acoustics, Speech, & Signal Processing*, 33(6):1461–1470, December 1985.
- [305] G. Matz and F. Hlawatsch. "Time-frequency formulation and design of optimal detectors". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 213–216, Paris, 18–21 June 1996.
- [306] G. Matz and F. Hlawatsch. "Time-frequency methods for signal detection with application to the detection of knock in car engines". In *Proc. Ninth IEEE Workshop on Statistical Signal and Array Processing (SSAP-98)*, pages 196–199, Portland, OR, 14–16 September 1998.
- [307] G. Matz and F. Hlawatsch. "Time-frequency transfer function calculus (symbolic calculus) of linear time-varying systems (linear operators) based on a generalized underspread theory". J. of Mathematical Physics, 39(8):4041–4070, August 1998. Special Issue on Wavelet and Time-Frequency Analysis.
- [308] G. Matz and F. Hlawatsch. "Time-varying spectra for underspread and overspread nonstationary processes". In *Proc. 32nd Asilomar Conf. on Signals, Systems, and Computers*, pages 282–286, Pacific Grove, CA, 1–4 November 1998.
- [309] G. Matz and F. Hlawatsch. "Minimax robust time-frequency filters for nonstationary signal estimation". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'99)*, pages 1333–1336, Phoenix, AZ, 15–19 March 1999.

- [310] G. Matz and F. Hlawatsch. "Time-frequency subspace detectors and application to knock detection". Archiv für Elektronik und Übertragungstechnik (Internat. J. of Electronics & Communications), 53(6):379–385, December 1999.
- [311] G. Matz and F. Hlawatsch. "Minimax robust nonstationary signal estimation based on a p-point uncertainty model". J. Franklin Institute, 337(4):403–419, July 2000.
- [312] G. Matz and F. Hlawatsch. "Linear time-frequency filters: On-line algorithms and applications". In A. Papandreou-Suppappola, editor, *Applications in Time-Frequency Signal Processing*, chapter 6, pages 205–271. CRC Press, Boca Raton, FL, 2002.
- [313] G. Matz and F. Hlawatsch. "Time-frequency projection filters: Online implementation, subspace tracking, and application to interference excision". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'02)*, pages 1213–1216, Orlando, FL, 13–17 May 2002.
- [314] G. Matz, F. Hlawatsch, and W. Kozek. "Generalized evolutionary spectral analysis and the Weyl spectrum of nonstationary random processes". *IEEE Trans. Signal Processing*, 45(6):1520–1534, June 1997.
- [315] G. Matz, F. Hlawatsch, and A. Raidl. "Signal-adaptive robust time-varying Wiener filters: Best subspace selection and statistical analysis". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'01)*, pages 3945–3948, Salt Lake City, UT, 7–11 May 2001.
- [316] G. Matz and A. Raidl. "Robust detection of nonstationary random signals belonging to p-point uncertainty classes". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'03)*, pages 641–644, Hong Kong, scheduled 6–10 April 2003.
- [317] A. C. McBride and F. H. Kerr. "On Namias's fractional Fourier transforms". *IMA J. of Applied Mathematics*, 39(2):159–175, 1987.
- [318] M. R. McClure and L. Carin. "Matching pursuits with a wave-based dictionary". *IEEE Trans. Signal Processing*, 45(12):2912–2927, December 1997.
- [319] W. Mecklenbräuker and F. Hlawatsch, editors. The Wigner Distribution—Theory and Applications in Signal Processing. Elsevier, Amsterdam, 1997.
- [320] M. Mesbah and B. Boashash. "Reduced bias time-frequency peak filtering". In *Proc. Sixth Internat. Symp. on Signal Processing and its Applications (ISSPA'01)*, volume 1, pages 327–330, Kuala Lumpur, 13–16 August 2001.
- [321] M. Mesbah and B. Boashash. "Performance comparison of seizure detection methods using EEG of newborns for implementation of a DSP subsystem". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'02)*, Orlando, FL, 13–17 May 2002. Paper no. 1932.
- [322] Y. Meyer. Wavelets: Algorithms and applications. Soc. for Industrial and Applied Mathematics, Philadelphia, PA, 1993. Translated and revised by Robert D. Ryan. Original French title: Ondelettes et algorithems concurrents.
- [323] Z.-H. Michalopoulou. "Underwater transient signal processing: Marine mammal identification, localization, and source signal deconvolution". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'97)*, volume 1, pages 503–506, Munich, 21–24 April 1997.
- [324] R. K. Mobley. Vibration Fundamentals. Newnes, Boston, 1999.

- [325] A. Monti, C. Medigue, and L. Mangin. "Instantaneous parameter estimation in cardiovascular time series by harmonic and time-frequency analysis". *IEEE Trans. Biomedical Engineering*, 49(12):1547–1556, December 2002.
- [326] M. R. Morelande, B. Barkat, and A. M. Zoubir. "Statistical performance comparison of a parametric and a non-parametric method for IF estimation of random amplitude linear FM signals in additive noise". In *Proc. Tenth IEEE Workshop on Statistical Signal and Array Processing (SSAP-2000)*, pages 262–266, Pocono Manor, PA, 14–16 August 2000.
- [327] D. R. Morgan and T. M. Smith. "Coherence effects on the detection performance of quadratic array processors with application to large-array matched-field beamforming". J. Acoustical Soc. of America, 87(2):737–747, February 1990.
- [328] J. M. Morris and Y. Lu. "Generalized Gabor expansions of discrete-time signals in $l^2(\mathbb{Z})$ via biorthogonal-like sequences". *IEEE Trans. Signal Processing*, 44(6):1378–1391, June 1996.
- [329] S. H. Nawab and T. F. Quatieri. "Short-time Fourier transform". In J. S. Lim and A. V. Oppenheim, editors, *Advanced Topics in Signal Processing*, chapter 6, pages 289–337. Prentice-Hall, Englewood Cliffs, NJ, 1988.
- [330] A. W. Naylor and G. R. Sell. *Linear Operator Theory in Engineering and Science*. Springer, New York, 2nd edition, 1982.
- [331] D. E. Newland. "Time-frequency and time-scale analysis by harmonic wavelets". In A. Prochazka, J. Uhlir, P. J. W. Rayner, and N. G. Kingsbury, editors, Signal Analysis and Prediction, chapter 1. Birkhäuser, Boston, MA, 1998.
- [332] R. M. Nickel, T.-H. Sang, and W. J. Williams. "A new signal adaptive approach to positive time-frequency distributions with suppressed interference terms". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'98)*, volume 3, pages 1777–1780, Seattle, 12–15 May 1998.
- [333] A. H. Nuttall. "On the quadrature approximation to the Hilbert transform of modulated signals". *Proc. IEEE*, 54:1458–1459, 1966.
- [334] A. H. Nuttall. "Efficient evaluation of polynomials and exponentials of polynomials for equispaced arguments". *IEEE Trans. Acoustics, Speech, & Signal Processing*, 35(10):1486–1487, October 1987.
- [335] S. C. Olhede and A. T. Walden. "Generalized Morse wavelets". *IEEE Trans. Signal Processing*, 50(11):2661–2670, November 2002.
- [336] P. M. Oliveira and V. Barroso. "Uncertainty in the time-frequency plane". In *Proc. Tenth IEEE Workshop on Statistical Signal and Array Processing (SSAP-2000)*, pages 607–611, Pocono Manor, PA, 14–16 August 2000.
- [337] J. C. O'Neill and W. J. Williams. "Shift-covariant time-frequency distributions of discrete signals". *IEEE Trans. Signal Processing*, 47(1):133–146, January 1999.
- [338] P. O'Shea. "An iterative algorithm for estimating the parameters of polynomial phase signals". In *Proc. Fourth Internat. Symp. on Signal Processing and its Applications (ISSPA'96)*, volume 2, pages 730–731, Gold Coast, Australia, 25–30 August 1996.
- [339] A. Ouldali and M. Benidir. "Statistical analysis of polynomial phase signals affected by multiplicative and additive noise". *Signal Processing*, 78(1):19–42, October 1999.

- [340] H. M. Ozaktas, O. Arıkan, M. A. Kutay, and G. Bozdağı. "Digital computation of the fractional Fourier transform". *IEEE Trans. Signal Processing*, 44(9):2141–2150, September 1996.
- [341] H. M. Ozaktas, B. Barshan, D. Mendlovic, and L. Onural. "Convolution, filtering, and multiplexing in fractional Fourier domains and their relationship to chirp and wavelet transforms". *J. Optical Soc. of America A*, 11:547–559, February 1994.
- [342] H. M. Ozaktas, M. A. Kutay, and D. Mendlovic. "Introduction to the fractional Fourier transform and its applications". In P. W. Hawkes, B. Kazan, and T. Mulvey, editors, *Advances in Imaging & Electron Physics—Vol. 106*, chapter 4, pages 239–291. Academic Press, San Diego, February 1999.
- [343] C. H. Page. "Instantaneous power spectra". J. of Applied Physics, 23(1):103–106, January 1952.
- [344] A. Papandreou, F. Hlawatsch, and G. F. Boudreaux-Bartels. "The hyperbolic class of quadratic time-frequency representations—Part I: Constant-Q warping, the hyperbolic paradigm, properties, and members". *IEEE Trans. Signal Processing*, 41(12):3425–3444, December 1993. Special Issue on Wavelets and Signal Processing.
- [345] A. Papandreou-Suppappola. "Generalized time-shift covariant quadratic time-frequency representations with arbitrary group delays". In *Proc. 29th Asilomar Conf. on Signals, Systems, and Computers*, pages 553–557, Pacific Grove, CA, October–November 1995.
- [346] A. Papandreou-Suppappola, editor. Applications in Time-Frequency Signal Processing. CRC Press, Boca Raton, FL, 2002.
- [347] A. Papandreou-Suppappola, F. Hlawatsch, and G. F. Boudreaux-Bartels. "Power class time-frequency representations: Interference geometry, smoothing, and implementation". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 193–196, Paris, 18–21 June 1996.
- [348] A. Papandreou-Suppappola, F. Hlawatsch, and G. F. Boudreaux-Bartels. "Quadratic time-frequency representations with scale covariance and generalized time-shift covariance: A unified framework for the affine, hyperbolic, and power classes". *Digital Signal Processing: A Review Journal*, 8(1):3–48, 1998.
- [349] A. Papandreou-Suppappola, R. L. Murray, B. G. Iem, and G. F. Boudreaux-Bartels. "Group delay shift covariant quadratic time-frequency representations". *IEEE Trans. Signal Processing*, 49(11):2549–2564, November 2001.
- [350] A. Papandreou-Suppappola and S. B. Suppappola. "Adaptive time-frequency representations for multiple structures". In *Proc. Tenth IEEE Workshop on Statistical Signal and Array Processing (SSAP-2000)*, pages 579–583, Pocono Manor, PA, 14–16 August 2000.
- [351] A. Papandreou-Suppappola and S. B. Suppappola. "Analysis and classification of time-varying signals with multiple time-frequency structures". *IEEE Signal Processing Letters*, 9(3):92–95, March 2002.
- [352] A. Papoulis. Signal analysis. McGraw-Hill, New York, 1977.
- [353] A. Papoulis. "Random modulation: A review". IEEE Trans. Acoustics, Speech, & Signal Processing, 31(1):96–105, February 1983.

- [354] A. Papoulis. Probability, Random Variables, and Stochastic Processes. McGraw-Hill, New York, 3rd edition, 1991.
- [355] T. W. Parks and R. G. Shenoy. "Time-frequency concentrated basis functions". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'90)*, pages 2459–2462, Albuquerque, NM, 3–6 April 1990.
- [356] L. Parra and C. Spence. "Convolutive blind separation of non-stationary sources". *IEEE Trans. on Speech & Audio Processing*, 8(3):320–327, May 2000.
- [357] J. D. Parsons. The Mobile Radio Propagation Channel. Pentech Press, London, 1992.
- [358] B. A. Paya, I. I. Esat, and M. N. M. Badi. "Artificial neural network based fault diagnostics of rotating machinery using wavelet transforms as a preprocessor". *J. Mechanical Systems and Signal Processing*, 11(5):751–765, September 1997.
- [359] S. Peleg and B. Friedlander. "Discrete polynomial-phase transform". *IEEE Trans. Signal Processing*, 43(8):1901–1914, August 1995.
- [360] S. Peleg and B. Friedlander. "Multicomponent signal analysis using the polynomial-phase transform". *IEEE Trans. Aerospace & Electronic Systems*, 32(1):378–386, January 1996.
- [361] S. Peleg and B. Porat. "Estimation and classification of polynomial-phase signals". *IEEE Trans. Information Theory*, 37(2):422–430, March 1991.
- [362] S. Peleg and B. Porat. "Linear FM signal parameter estimation from discrete-time observations". *IEEE Trans. Aerospace & Electronic Systems*, 27(4):607–616, July 1991.
- [363] A. Persson, T. Ottosson, and E. Strom. "Time-frequency localized CDMA for downlink multi-carrier systems". In *Proc. Seventh Internat. Symp. on Spread Spectrum Techniques and Applications (ISSSTA-02)*, volume 1, pages 118–122, Prague, 2–5 September 2002.
- [364] B. Picinbono. "On Instantaneous Amplitude and Phase of Signals". *IEEE Trans. Signal Processing*, 45(3):552–560, March 1997.
- [365] B. Picinbono and W. Martin. "Représentation des signaux par amplitude et phase instantanées". Ann. Télécommunications, 38:179–190, 1983.
- [366] A. G. Piersol. "Power spectra measurements for space vibration data". J. Spacecraft and Rockets, 4:1613, December 1967.
- [367] S. Pon Varma, A. Papandreou-Suppappola, and S. B. Suppappola. "Detecting faults in structures using time-frequency techniques". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'01)*, volume 6, pages 3593–3596, Salt Lake City, UT, 7–11 May 2001.
- [368] S. Pon Varma, A. Papandreou-Suppappola, and S. B. Suppappola. "Matching pursuit classification for time-varying acoustic emissions". In *Proc. 35th Asilomar Conf. on Signals, Systems, and Computers*, Pacific Grove, CA, 4–7 November 2001. Paper TA2-3.
- [369] H. V. Poor. An Introduction to Signal Detection and Estimation. Springer, New York, 1988.
- [370] B. Porat and B. Friedlander. "Asymptotic statistical analysis of the high-order ambiguity function for parameter estimation of polynomial phase signal". *IEEE Trans. Information Theory*, 42(3):995–1001, May 1996.

- [371] M. R. Portnoff. "Time-frequency representation of digital signals and systems based on short-time Fourier analysis". *IEEE Trans. Acoustics, Speech, & Signal Processing*, 28(1):55–69, February 1980.
- [372] S. Prabhakar, A. S. Sekhar, and A. R. Mohanty. "Detection and monitoring of cracks in a rotor-bearing system using wavelet transforms". *J. Mechanical Systems and Signal Processing*, 15(2):447–450, March 2001.
- [373] R. Price and E. M. Hofstetter. "Bounds on the volume and height distributions of the ambiguity function". *IEEE Trans. Information Theory*, 11:207–214, 1965.
- [374] M. B. Priestley. Spectral Analysis and Time Series—Part II. Academic Press, London, 1981.
- [375] M. B. Priestly. "Evolutionary spectra and non-stationary processes". J. Royal Statistical Soc. (Series B), 27(2):204–237, 1965.
- [376] J. G. Proakis. Digital Communications. McGraw-Hill, New York, 3rd edition, 1995.
- [377] G. R. Putland and B. Boashash. "Can a signal be both monocomponent and multicomponent?". In *Third Australasian Workshop on Signal Processing Applications* (WoSPA 2000), Brisbane, Australia, 14–15 December 2000. Paper no. 32.
- [378] S. Qian. Introduction to Time-frequency and Wavelet Transforms. Prentice-Hall, Englewood Cliffs, NJ, 2002.
- [379] S. Qian and D. Chen. "Decomposition of the Wigner distribution and time-frequency distribution series". *IEEE Trans. Signal Processing*, 42(10):2836–2842, October 1994.
- [380] S. Qian and D. Chen. *Joint Time-Frequency Analysis: Methods & Applications*. Prentice-Hall, Upper Saddle River, NJ, 1996.
- [381] S. Qian and D. Chen. "Joint time-frequency analysis". *IEEE Signal Processing Magazine*, 16(2):52–65, March 1999.
- [382] S. Qian, Y. Rao, and D. Chen. "A fast Gabor spectrogram". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP 2000)*, volume 2, pages 653–656, Istanbul, 5–9 June 2000.
- [383] R. S. Ramineni, M. G. Amin, and A. R. Lindsey. "Performance analysis of subspace projection techniques for interference excision in DSSS communications". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP 2000)*, volume 5, pages 2825–2828, Istanbul, 5–9 June 2000.
- [384] L. Rankine and M. Mesbah. "Significant atom determination of basis pursuit decomposition". In *Proc. Seventh Internat. Symp. on Signal Processing and its Applications (ISSPA'03)*, pages 577–580, Paris, 1–4 July 2003.
- [385] A. M. Rao and D. L. Jones. "Efficient structures for quadratic time-frequency and time-scale array processors". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 397–400, Pittsburgh, PA, 6–9 October 1998.
- [386] A. M. Rao and D. L. Jones. "Nonstationary array signal detection using time-frequency and time-scale representations". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'98)*, volume 4, pages 1989–1992, Seattle, 12–15 May 1998.
- [387] A. M. Rao and D. L. Jones. "A denoising approach to multisensor signal estimation". *IEEE Trans. Signal Processing*, 48(5):1225–1234, May 2000.

- [388] T. S. Rappaport. Wireless Communications: Principles & Practice. Prentice-Hall, Upper Saddle River, NJ, 1996.
- [389] T. R. Reed and H. Wechsler. "Segmentation of textured images and Gestalt organization using spatial/spatial-frequency representations". *IEEE Trans. Pattern Analysis & Machine Intelligence*, 12(1):1–12, January 1990.
- [390] D. C. Reid, A. M. Zoubir, and B. Boashash. "Aircraft flight parameter estimation based on passive acoustic techniques using the polynomial Wigner-Ville distribution". *J. Acoustical Soc. of America*, 102(1):207–23, July 1997.
- [391] A. Reilly, G. Frazer, and B. Boashash. "Analytic signal generation—Tips and traps". *IEEE Trans. Signal Processing*, 42(11):3241–3245, November 1994.
- [392] G. Reina and B. Porat. "Comparative performance analysis of two algorithms for instantaneous frequency estimation". In *Proc. Eighth IEEE Workshop on Statistical Signal and Array Processing (SSAP-96)*, pages 448–451, Corfu, Greece, 24–26 June 1996.
- [393] C. Richard. "Time-frequency-based detection using discrete-time discrete-frequency Wigner distributions". *IEEE Trans. Signal Processing*, 50(9):2170–2176, September 2002.
- [394] C. Richard and R. Lengellé. "Data-driven design and complexity control of time-frequency detectors". Signal Processing, 77(1):37–48, August 1999.
- [395] M. S. Richman, T. W. Parks, and R. G. Shenoy. "Discrete-time, discrete-frequency time-frequency analysis". *IEEE Trans. Signal Processing*, 46(6):1517–1527, June 1998.
- [396] D. C. Rife and R. R. Boorstyn. "Single-tone parameter estimation from discrete-time observations". *IEEE Trans. Information Theory*, 20(5):591–598, September 1974.
- [397] A. W. Rihaczek. "Signal energy distribution in time and frequency". *IEEE Trans. Information Theory*, 14(3):369–374, May 1968.
- [398] A. W. Rihaczek. Principles of high-resolution radar. McGraw-Hill, New York, 1969. Reprinted Los Altos, CA: Peninsula Publishing, 1985.
- [399] M. D. Riley. Speech Time-Frequency Representations. Kluwer, 1989.
- [400] O. Rioul and P. Flandrin. "Time-scale energy distributions: A general class extending wavelet transforms". *IEEE Trans. Signal Processing*, 40(7):1746–1757, July 1992.
- [401] B. Ristic and B. Boashash. "Kernel design for time-frequency signal analysis using the Radon transform". *IEEE Trans. Signal Processing*, 41(5):1996–2008, May 1993.
- [402] B. Ristic and B. Boashash. "Relationship between the polynomial and higher order Wigner-Ville distribution". *IEEE Signal Processing Letters*, 2(12):227–229, December 1995.
- [403] B. Ristic and B. Boashash. "Instantaneous frequency estimation of quadratic and cubic polynomial FM signals using the cross polynomial Wigner-Ville distribution". *IEEE Trans. Signal Processing*, 44:1549–1553, 1996.
- [404] G. Roberts, A. M. Zoubir, and B. Boashash. "Non-stationary, narrowband Gaussian signal discrimination in time-frequency space". In Wysocki et al. [506], chapter 18, pages 159–166.
- [405] T. D. Rossing. *The Science of Sound*. Addison-Wesley, Reading, MA, 2nd edition, 1990.
- [406] W. Rudin. Real and complex analysis. McGraw-Hill, New York, 1987.

- [407] B. Samimy and G. Rizzoni. "Mechanical signature analysis using time-frequency signal processing: Application to internal combustion engine knock detection". *Proc. IEEE*, 84(9):1130–1343, September 1996.
- [408] T.-H. Sang and W. J. Williams. "Rényi information and signal-dependent optimal kernel design". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'95)*, volume 2, pages 997–1000, Detroit, 9–12 May 1995.
- [409] N. Sang-Won and E. J. Powers. "Volterra series representation of time-frequency distributions". *IEEE Trans. Signal Processing*, 51(6):1532–1537, July 2003.
- [410] S. Santoso, E. J. Powers, W. M. Grady, and P. Hofmann. "Power quality assessment via wavelet transform analysis". *IEEE Trans. Power Delivery*, 11(2):924–930, April 1996.
- [411] G. J. Saulnier, M. J. Medley, and P. K. Das. "Wavelets and filter banks in spread spectrum communication systems". In A. N. Akansu and M. J. T. Smith, editors, *Subband and Wavelet Transforms: Design and Applications*, chapter 10, pages 309–346. Kluwer, Norwell, MA, 1996.
- [412] A. M. Sayeed and B. Aazhang. "Joint multipath-Doppler diversity in mobile wireless communications". *IEEE Trans. Communications*, 47:123–132, January 1999.
- [413] A. M. Sayeed and D. J. Jones. "Optimal detection using bilinear time-frequency and time-scale representations". *IEEE Trans. Signal Processing*, 43(12):2872–2883, December 1995.
- [414] A. M. Sayeed and D. L. Jones. "A canonical covariance-based method for generalized joint signal representations". *IEEE Signal Processing Letters*, 3(4):121–123, April 1996.
- [415] A. M. Sayeed and D. L. Jones. "Integral transforms covariant to unitary operators and their implications for joint signal representations". *IEEE Trans. Signal Processing*, 44(6):1365–1377, June 1996.
- [416] A. M. Sayeed and D. L. Jones. "Optimum quadratic detection and estimation using generalized joint signal representations". *IEEE Trans. Signal Processing*, 44(12):3031–3043, December 1996.
- [417] A. M. Sayeed, A. Sendonaris, and B. Aazhang. "Multiuser detection in fast fading multipath environments". *IEEE J. on Selected Areas in Communications*, 16:1691–1701, December 1998.
- [418] L. L. Scharf and B. Friedlander. "Toeplitz and Hankel kernels for estimating time-varying spectra of discrete-time random processes". *IEEE Trans. Signal Processing*, 49(1):179–189, January 2001.
- [419] M. O. Scully and L. Cohen. "Quasi-probability distributions for arbitrary operators". In Y. S. Kim and W. W. Zachary, editors, *The Physics of Phase Space: Nonlinear Dynamics and Chaos, Geometric Quantization, and Wigner Functions*, number 278 in Lecture Notes in Physics, pages 253–263. Springer, Berlin, 1987. Proc. First Internat. Conf. on the Physics of Phase Space, University of Maryland, College Park, MD, 20–23 May 1986.
- [420] J. P. Sessarego, J. Sageloli, P. Flandrin, and M. Zakharia. "Time-frequency Wigner-Ville analysis of echoes scattered by a spherical shell". In J.-M. Combes, A. Grossmann, and P. Tchamitchian, editors, *Wavelets: Time-frequency Methods and Phase Space*, pages 147–153. Springer, 1989. Proc. of the Internat. Conf., Marseille, 14–18 December, 1987. 315pp.

- [421] A. Z. Sha'ameri, B. Boashash, and I. Ismail. "Design of signal dependent kernel functions for digital modulated signals". In *Proc. Fourth Internat. Symp. on Signal Processing and its Applications (ISSPA '96)*, volume 2, pages 527–528, Gold Coast, Australia, 25–30 August 1996.
- [422] R. G. Shenoy and T. W. Parks. "The Weyl correspondence and time-frequency analysis". *IEEE Trans. Signal Processing*, 42(2):318–331, February 1994.
- [423] Y. Shin, A. C. Parsons, E. J. Powers, and W. M. Grady. "Time-frequency analysis of power system disturbance signals for power quality". In *Proc. IEEE Power Engineering Soc. Summer Meeting*, volume 1, pages 402–407, Edmonton, AL (Canada), 18–22 July 1999.
- [424] Y. Shin, E. J. Powers, W. M. Grady, and S. C. Bhatt. "Effects of dispersion on disturbance propagation on high voltage transmission lines". In *Proc. IEEE Power Engi*neering Soc. Summer Meeting, volume 2, pages 851–854, Seattle, WA (USA), 16–20 July 2000.
- [425] W. M. Siebert. "Studies of Woodward's uncertainty function". Quarterly Progress Report (MIT Electronics Research Lab, Cambridge, MA), pages 90–94, 1958.
- [426] J. A. Sills and E. W. Kamen. "Time-varying matched filters". Circuits, Systems, & Signal Processing, 15(5):609–630, 1996.
- [427] M. K. Simon, J. K. Omura, R. A. Scholtz, and B. K. Levitt. *Spread Spectrum Communications* (3 vols.). Computer Science Press, Rockville, MD, 1985.
- [428] L. Sirovich and B. W. Knight. "On the eigentheory of operators which exhibit a slow variation". Quarterly of Applied Mathematics, 38:469–488, 1980.
- [429] D. Slepian. "On bandwidth". Proc. IEEE, 64(3):292-300, March 1976.
- [430] D. T. Smithey, M. Beck, M. G. Raymer, and A. Faridani. "Measurement of the Wigner distribution and the density matrix of a light mode using optical homodyne tomography: Application to squeezed states and the vacuum". *Physical Review Letters*, 70:1244–1247, 1993.
- [431] T. Södertröm and P. Stoica. System Identification. Prentice-Hall, Englewood Cliffs. NJ, 1989.
- [432] K. A. Sostrand. "Mathematics of the time-varying channel". In *Proc. NATO Advanced Study Inst. on Signal Processing with Emphasis on Underwater Acoustics*, volume 2, pages 25.1–25.20, 1968.
- [433] L. Stanković. "An analysis of some time-frequency and time-scale distributions". *Ann. Télécommunications*, 49(9/10):505–517, September/October 1994.
- [434] L. Stanković. "An analysis of Wigner higher order spectra of multicomponent signals". Ann. Télécommunications, 49(3/4):132–136, March/April 1994.
- [435] L. Stanković. "A method for time-frequency analysis". *IEEE Trans. Signal Processing*, 42(1):225–229, January 1994.
- [436] L. Stanković. "Multitime definition of the Wigner higher order distribution: L-Wigner distribution". *IEEE Signal Processing Letters*, 1(7):106–109, July 1994.
- [437] L. Stanković. "A method for improved distribution concentration in the time-frequency analysis of the multicomponent signals using the L-Wigner distribution". *IEEE Trans. Signal Processing*, 43(5):1262–1268, May 1995.

- [438] L. Stanković. "Auto-term representation by the reduced interference distributions: A procedure for kernel design". *IEEE Trans. Signal Processing*, 44(6):1557–1563, June 1996.
- [439] L. Stanković. "Highly concentrated time-frequency distributions: Pseudo-quantum signal representation". *IEEE Trans. Signal Processing*, 45(3):543–551, March 1997.
- [440] L. Stanković. "On the time-frequency analysis based filtering". Ann. Télécommunications, 55(5/6):216–225, May/June 2000.
- [441] L. Stanković. "A measure of some time-frequency distributions concentration". Signal Processing, 81(3):621–631, March 2001.
- [442] L. Stanković. "Analysis of noise in time-frequency distributions". *IEEE Signal Processing Letters*, 9(9):286–289, September 2002.
- [443] L. Stanković. "Time-frequency distributions with complex argument". *IEEE Trans. Signal Processing*, 50(3):475–486, March 2002.
- [444] L. Stanković, T. Alieva, and M. Bastiaans. "Fractional-Fourier-domain weighted Wigner distribution". In *Proc. Eleventh IEEE Workshop on Statistical Signal Processing*, pages 321–324, Singapore, 6–8 August 2001.
- [445] L. Stanković and J. F. Böhme. "Time-frequency analysis of multiple resonances in combustion engine signals". *Signal Processing*, 79(1):15–28, November 1999.
- [446] L. Stanković and V. Ivanović. "Further results on the minimum variance time-frequency distributions kernels". *IEEE Trans. Signal Processing*, 45(6):1650–1655, June 1997.
- [447] L. Stanković and V. Katkovnik. "The Wigner distribution of noisy signals with adaptive time-frequency varying window". *IEEE Trans. Signal Processing*, 47(4):1099–1108, April 1999.
- [448] L. Stanković and V. Katkovnik. "Instantaneous frequency estimation using the higher order L-Wigner distributions with the data driven order and window length". *IEEE Trans. Information Theory*, 46(1):302–311, January 2000.
- [449] L. Stanković and S. Stanković. "On the Wigner distribution of the discrete-time noisy signals with application to the study of quantization effects". *IEEE Trans. Signal Processing*, 42(7):1863–1867, July 1994.
- [450] L. Stanković and S. Stanković. "An analysis of instantaneous frequency representation using time-frequency distributions—Generalized Wigner distribution". *IEEE Trans. Signal Processing*, 43(2):549–552, February 1995.
- [451] L. Stanković, S. Stanković, and I. Djurović. "Architecture for realization of the cross-terms free polynomial Wigner-Ville distribution". In *Proc. IEEE Internat. Conf.* on Acoustics, Speech and Signal Processing (ICASSP'97), volume III, pages 2053–2056, Munich, 21–24 April 1997.
- [452] L. Stanković, S. Stanković, and I. Djurović. "Space/spatial frequency based filtering". *IEEE Trans. Signal Processing*, 48(8):2343–2352, August 2000.
- [453] S. Stanković. "About time-variant filtering of speech signals with time-frequency distributions for hands-free telephone systems". Signal Processing, 80(9):1777–1785, September 2000.

- [454] S. Stanković and L. Stanković. "Approach to the polynomial Wigner distributions". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 153–156, Paris, 18–21 June 1996.
- [455] S. Stanković and L. Stanković. "Introducing time-frequency distribution with a 'complex-time' argument". *Electronics Letters*, 32(14):1265–1267, July 1996.
- [456] S. Stanković, L. Stanković, and Z. Uskoković. "On the local frequency, group shift, and cross-terms in some multidimensional time-frequency distributions: A method for multidimensional time-frequency analysis". *IEEE Trans. Signal Processing*, 43(7):1719–1725, July 1995.
- [457] S. Stanković and J. Tilp. "Time-varying filtering of speech signals using linear prediction". *Electronics Letters*, 36(8):763–764, April 2000.
- [458] W. J. Staszewski, K. Worden, and G. R. Tomlinson. "Time-frequency analysis in gearbox fault detection using the Wigner-Ville distribution and pattern recognition". *J. Mechanical Systems and Signal Processing*, 11(5):673–692, September 1997.
- [459] N. Stevenson, E. Palmer, J. Smeathers, and B. Boashash. "The BT product as a signal dependent sample size estimate in hypothesis testing: An application to linear/nonlinear discrimination in bandwidth limited systems". In Proc. Seventh Internat. Symp. on Signal Processing and its Applications (ISSPA'03), pages 551–554, Paris, 1–4 July 2003.
- [460] L. R. O. Storey. "An investigation of whistling atmospherics". Phil. Trans. Roy. Soc., A246:113–141, 1953.
- [461] G. Strang and T. Q. Nguyen. Wavelets and Filter Banks. Wellesley-Cambridge Press, Wellesley, MA, 1996.
- [462] V. Sucic and B. Boashash. "Optimisation algorithm for selecting quadratic time-frequency distributions: Performance results and calibration". In *Proc. Sixth Internat. Symp. on Signal Processing and its Applications (ISSPA'01)*, volume 1, pages 331–334, Kuala Lumpur, 13–16 August 2001.
- [463] V. Sucic and B. Boashash. "Parameter selection for optimising time-frequency distributions and measurements of time-frequency characteristics of non-stationary signals". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'01)*, volume 6, pages 3557–3560, Salt Lake City, UT, 7–11 May 2001.
- [464] V. Sucic and B. Boashash. "Selecting the optimal time-frequency distribution for real-life multicomponent signals under given constraints". In *Proc. Eleventh European Signal Processing Conf. (EUSIPCO-02)*, volume 1, pages 141–144, Toulouse, 3–6 September 2002.
- [465] V. Sucic and B. Boashash. "An approach for selecting a real-life signal best-performing time-frequency distribution". In *Proc. Seventh Internat. Symp. on Signal Processing and its Applications (ISSPA'03)*, volume 1, pages 100–104, Paris, 1–4 July 2003.
- [466] V. Sucic, B. Boashash, and K. Abed-Meraim. "A normalised performance measure for quadratic time-frequency distributions". In *Proc. Second IEEE Internat. Symp. on Signal Processing and Information Technology (ISSPIT'02)*, pages 463–466, Marrakech, Morocco, 18–21 December 2002.

- [467] S. M. Sussman. "Least-squares synthesis of radar ambiguity functions". *IRE Trans. Information Theory*, 8:246–254, April 1962.
- [468] H. Suzuki and F. Kobayashi. "A method of two-dimensional spectral analysis using the Wigner distribution". *Electronics & Communications in Japan, Part III: Fundamental Electronic Science*, 75(1):1006–1013, January 1992.
- [469] H. H. Szu. "Two-dimensional optical processing of one-dimensional acoustic data". Optical Engineering, 21(5):804–813, September–October 1982.
- [470] M. T. Taner, F. Koehler, and R. E. Sheriff. "Complex seismic trace analysis". *Geophysics*, 44(6):1041–1063, June 1979.
- [471] S. Thangavelu. Lectures on Hermite and Laguerre Expansions. Princeton University Press, Princeton, NJ, 1993.
- [472] S. A. Tretter. "Estimating the frequency of a noisy sinusoid by linear regression". *IEEE Trans. Information Theory*, 31(6):832–835, November 1985.
- [473] F. Tupin, H. Maître, J.-F. Mangin, J.-M. Nicolas, and E. Pechersky. "Detection of linear features in SAR images: Application to road network extraction". *IEEE Trans. Geoscience & Remote Sensing*, 36(2):434–453, March 1998.
- [474] D. Vakman. "On the analytic signal, the Teager-Kaiser energy algorithm, and other methods for defining amplitude and frequency". *IEEE Trans. Signal Processing*, 44(4):791–797, April 1996.
- [475] D. E. Vakman. Sophisticated Signals and the Uncertainty Principle in Radar. Springer, New York, 1968. Translated by K. N. Trirogoff; edited by E. Jacobs.
- [476] A. J. van Leest. Non-separable Gabor schemes: Their design and implementation. PhD thesis, Eindhoven University of Technology, Eindhoven, Netherlands, 2001.
- [477] H. G. van Steenis, W. L. J. Martens, and J. H. M. Tulen. "Time-frequency parameters of heart-rate variability". *IEEE Engineering in Medicine & Biology Magazine*, 21(4):46–58, July-August 2002.
- [478] H. L. L. Van Trees. Detection, Estimation, and Modulation Theory, volume I: "Detection, Estimation, and Linear Modulation Theory". Wiley, New York, 1968. Reprinted 2001.
- [479] H. L. L. Van Trees. *Detection, Estimation, and Modulation Theory*, volume III: "Radar-Sonar Signal Processing and Gaussian Signals in Noise". Wiley, New York, 1971. Reprinted Malabar, FL: Krieger, 1992. Reprinted New York: Wiley, 2001.
- [480] S. V. Vaseghi. Advanced Signal Processing and Digital Noise Reduction. Wiley and Teubner, 1996.
- [481] E. F. Velez and H. Garudadri. "Speech analysis based on smoothed Wigner-Ville distribution". In B. Boashash, editor, *Time-Frequency Signal Analysis: Methods and Applications*, chapter 15, pages 351–374. Longman-Cheshire/Wiley, Melbourne/N.Y., 1992.
- [482] B. V. K. Vijaya Kumar and C. W. Carroll. "Performance of Wigner distribution function based detection methods". *Optical Engineering*, 23(6):732–737, November-December 1984.
- [483] J. Ville. "Théorie et applications de la notion de signal analytique". Cables et Transmissions, 2A(1):61–74, 1948. In French. English translation: I. Selin, Theory and applications of the notion of complex signal, Rand Corporation Report T-92 (Santa Monica, CA, August 1958).

- [484] K. Vogel and H. Risken. "Determination of quasiprobability distributions in terms of probability distributions for the rotated quadrature phase". *Physical Review A*, 40:2847–2849, 1989.
- [485] H. Vold and J. Leuridan. "High resolution order tracking at extreme slew rates using Kalman tracking filters". In *Proc. Noise & Vibration Conf. & Exposition*. Soc. of Automotive Engineers, Traverse City, MI, 17–20 May 1993. SAE paper no. 931288.
- [486] C. Wang and M. G. Amin. "Performance analysis of instantaneous frequency based interference excision techniques in spread spectrum communications". *IEEE Trans. Signal Processing*, 46(1):70–83, January 1998.
- [487] W. Wang; and D. H. Johnson. "Computing linear transforms of symbolic signals". *IEEE Trans. Signal Processing*, 50(3):628–634, March 2002.
- [488] J. Wexler and S. Raz. "Discrete Gabor expansions". Signal Processing, 21(3):207–221, November 1990.
- [489] A. D. Whalen. Detection of Signals in Noise. Academic Press, 1971.
- [490] L. B. White. "Transition kernels for bilinear time-frequency signal representations". *IEEE Trans. Signal Processing*, 39(2):542–544, February 1991.
- [491] L. B. White and B. Boashash. "Cross spectral analysis of nonstationary processes". *IEEE Trans. Information Theory*, 36(4):830–835, July 1990.
- [492] H. J. Whitehouse, B. Boashash, and J. M. Speiser. "High-resolution processing techniques for temporal and spatial signals". In M. Bouvet and G. Bienvenu, editors, *High-resolution methods in underwater acoustics*, chapter 4, pages 127–176. Springer, Berlin, 1991.
- [493] E. P. Wigner. "On the quantum correction for thermodynamic equilibrium". *Physics Review*, 40:749–759, June 1932.
- [494] W. J. Williams. "Reduced interference distributions: Biological applications and interpretations". *Proc. IEEE*, 84(9):1264–1280, September 1996.
- [495] W. J. Williams. "Recent advances in time-frequency representations: Some theoretical foundation". In M. Akay, editor, *Time Frequency and Wavelets in Biomedical Signal Processing*, chapter 1. IEEE/Wiley, New York, 1998.
- [496] W. J. Williams. "Reduced interference time-frequency distributions: Scaled decompositions and interpretations". In L. Debnath, editor, Wavelet Transforms and Time-Frequency Signal Analysis, chapter 12. Birkhäuser, Boston, 2001.
- [497] W. J. Williams and S. Aviyente. "Optimum window time-frequency distribution decompositions". In *Proc. 32nd Asilomar Conf. on Signals, Systems, and Computers*, pages 817–821, Pacific Grove, CA, 1–4 November 1998.
- [498] W. J. Williams and S. Aviyente. "Minimal-window time-frequency distributions". In *Proc. SPIE: Advanced Signal Processing Algorithms, Architectures, and Implementations IX*, volume 3807, pages 446–457. Soc. of Photo-optical Instrumentation Engineers, Denver, CO, 19–21 July 1999.
- [499] W. J. Williams, M. L. Brown, and A. O. Hero III. "Uncertainty, information and time-frequency distributions". In *Proc. SPIE: Advanced Signal Processing Algorithms, Architectures, and Implementations II*, volume 1566, pages 144–156. Soc. of Photo-optical Instrumentation Engineers, San Diego, 24–26 July 1991.

- [500] W. J. Williams and J. Jeong. "Reduced interference time-frequency distributions". In B. Boashash, editor, *Time-Frequency Signal Analysis: Methods and Applications*, chapter 3, pages 74–97. Longman-Cheshire/Wiley, Melbourne/N.Y., 1992.
- [501] W. J. Williams and J. C. O'Neill. "Decomposition of time-frequency distributions using scaled window spectrograms". In *Proc. SPIE: Advanced Signal Processing Algorithms*, volume 2563, pages 44–58. Soc. of Photo-optical Instrumentation Engineers, San Diego, CA, 10–12 July 1995.
- [502] W. J. Williams and T.-H. Sang. "Adaptive RID kernels which minimize time-frequency uncertainty". In *Proc. IEEE-SP Internat. Symp. on Time-Frequency & Time-Scale Analysis*, pages 96–99, Philadelphia, PA, 25–28 October 1994.
- [503] W. J. Williams, T.-H. Sang, J. C. O'Neill, and E. J. Zalubas. "Wavelet windowed time-frequency distribution decompositions". In *Proc. SPIE: Advanced Signal Processing Algorithms, Architectures, and Implementations VII*, volume 3162, pages 149–160. Soc. of Photo-optical Instrumentation Engineers, San Diego, July–August 1997.
- [504] J. C. Wood and D. T. Barry. "Tomographic time-frequency analysis and its application toward time-varying filtering and adaptive kernel design for multicomponent linear FM signals". *IEEE Trans. Signal Processing*, 42:2094–2104, 1994.
- [505] P. M. Woodward. Probability and Information Theory with Applications to Radar. Pergamon, London, 1953.
- [506] T. Wysocki, H. Razavi, and B. Honary, editors. *Digital Signal Processing for Communication Systems*. Number 403 in Kluwer Internat. Series in Engineering and Computer Science. Kluwer, Boston, MA, 1997.
- [507] X.-G. Xia. "System identification using chirp signals and time-variant filters in the joint time-frequency domain". *IEEE Trans. Signal Processing*, 45(8):2072–2084, August 1997.
- [508] X.-G. Xia and V. C. Chen. "A quantitative SNR analysis for the pseudo Wigner-Ville distribution". *IEEE Trans. Signal Processing*, 47(10):2891–2894, October 1999.
- [509] X.-G. Xia, Y. Owechko, B. H. Soffer, and R. M. Matic. "On generalized-marginal time-frequency distributions". *IEEE Trans. Signal Processing*, 44(11):2882–2886, November 1996.
- [510] X.-G. Xia and S. Qian. "Convergence of an iterative time-variant filtering based on discrete Gabor transform". *IEEE Trans. Signal Processing*, 47(10):2894–2899, October 1999.
- [511] X.-G. Xia, G. Wang, and V. Chen. "Quantitative SNR analysis for ISAR imaging using joint time-frequency analysis—Short time Fourier transform". *IEEE Trans. Aerospace & Electronic Systems*, 38(3):649–659, April 2002.
- [512] J. Yang. "Frequency domain noise suppression approaches in mobile telephone systems". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP'93)*, volume 2, pages 363–366, Minneapolis, 27–30 April 1993.
- [513] L. A. Zadeh. "Frequency analysis of variable networks". Proc. IRE, 3A-8:291–299, March 1950.
- [514] P. Zarjam, M. Mesbah, and B. Boashash. "Detection of newborn EEG seizure using optimal features based on discrete wavelet transform". In *Proc. IEEE Internat. Conf. on*

- Acoustics, Speech and Signal Processing (ICASSP'03), volume 2, pages 265–268, Hong Kong, scheduled 6–10 April 2003.
- [515] A. I. Zayed. "A class of fractional integral transforms: a generalization of the fractional Fourier transform". *IEEE Trans. Signal Processing*, 50(3):619–627, March 2002.
- [516] Y. Y. Zeevi, M. Zibulski, and M. Porat. "Multi-window Gabor schemes in signal and image representations". In H. G. Feichtinger and T. Strohmer, editors, *Gabor Analysis and Algorithms: Theory and Applications*, chapter 12, pages 381–407. Birkhäuser, Berlin/Boston, 1998.
- [517] F. Zhang, G. Bi, and Y. Q. Chen. "Tomography time-frequency transform". *IEEE Trans. Signal Processing*, 50(6):1289–1297, June 2002.
- [518] Y. Zhang and M. G. Amin. "Blind separation of sources based on their time-frequency signatures". In *Proc. IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (ICASSP 2000)*, volume 5, pages 3132–3135, Istanbul, 5–9 June 2000.
- [519] Y. Zhang and M. G. Amin. "Spatial averaging of time-frequency distributions for signal recovery in uniform linear arrays". *IEEE Trans. Signal Processing*, 48(10):2892–2902, October 2000.
- [520] Y. Zhang, W. Mu, and M. G. Amin. "Time-frequency maximum likelihood methods for direction finding". J. Franklin Institute, 337(4):483–497, July 2000.
- [521] Y. Zhang, W. Mu, and M. G. Amin. "Subspace analysis of spatial time-frequency distribution matrices". *IEEE Trans. Signal Processing*, 49(4):747–759, April 2001.
- [522] Y. Zhao, L. E. Atlas, and R. J. Marks II. "The use of cone-shaped kernels for generalized time-frequency representations of non-stationary signals". *IEEE Trans. Acoustics*, Speech, & Signal Processing, 38(7):1084–1091, July 1990.
- [523] H. Zheng, Z. Li, and X. Chen. "Gear fault diagnosis based on continuous wavelet transform". *J. Mechanical Systems and Signal Processing*, 16(2–3):447–457, March–May 2002.
- [524] Y. M. Zhu, R. Goutte, and M. Amiel. "On the use of two-dimensional Wigner-Ville distribution for texture segmentation". Signal Processing, 30(3):329–353, February 1993.
- [525] M. Zibulski and Y. Y. Zeevi. "Discrete multiwindow Gabor-type transforms". *IEEE Trans. Signal Processing*, 45(6):1428–1442, June 1997.
- [526] R. Zou, W. A. Cupples, K. R. Yip, N. H. Holstein-Rathlou, and K. Chon. "Time-varying properties of renal autoregulatory mechanisms". *IEEE Trans. Biomedical Engineering*, 49(10):1112–1120, October 2002.

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